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**MARKET FOR TRANSGENIC PRODUCT: THE CASE OF
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**THE ECONOMICS OF
TRANSGENIC HERBICIDE-TOLERANT CANOLA**

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ABSTRACT

A wide range of agricultural products developed using modern biotechnology techniques have recently been commercialized. One such product is transgenic herbicide-tolerant (HT) canola, which is now widely available to producers in western Canada. Such canola varieties contain one or more genes that are not part of the species' normal genetic makeup, and tolerate the application of a herbicide that would otherwise harm or kill the plant.

Many of the questions and concerns surrounding this new technology extend to crops other than canola and novel traits other than herbicide-tolerance. Many consumer are unsure whether they wish to consume transgenic plants, primarily for health safety reasons. This has led to the desire for segregation of transgenic crops and labelling requirements in some countries. Another general concern is that the novel gene(s) in a transgenic crop will be transferred to weedy relatives, possibly creating HT weeds that are difficult or impossible to control.

The objective of this thesis is to evaluate the overall economic consequences of HT canola for canola producers. This involves estimating the benefits and/or costs that may accrue at the crop production level, the effects of

consumer rejection of transgenic canola in an economically important canola export market, the possibility and effects of gene introgression, and the effects of recent restructuring in the seed, crop protection and agriculture biotechnology industries.

The value of producer surplus is used to measure the economic benefit resulting from the adoption of HT canola and the effects of consumer rejection of transgenic canola in an export market. The results indicate that segregation of transgenic and conventional canola represents a potential Pareto improvement for producers, and that without segregation producer welfare could decline significantly. A review of studies concerning gene introgression from canola to wild mustard and other weeds indicates that this is possible but not plausible. In the event it does occur, economic analysis of wild mustard infestation in canola shows that the economic benefit of HT canola disappears quickly. An examination of the seed and crop protection industries indicates that producers are realizing only part of the potential economic benefit of HT canola because firms supplying the seed are adding a markup to their marginal cost. As well, a greater degree of vertical integration may take place in the future for certain types of transgenic canola varieties.

The main conclusion of the thesis is that the potential economic benefit of HT canola resulting from lower production costs currently are greater than

the cost of segregation and the value of the markup on the technology, however gene introgression could erode this benefit.

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CHAPTER I

INTRODUCTION

1.1 Problem Setting

After years of laboratory research and field trials, a wide range of agricultural products developed using modern biotechnology techniques have reached the commercialization stage. One such product is transgenic herbicide-tolerant (HT) canola. It is transgenic because it contains one or more genes that are not part of its usual genetic makeup, and HT because the canola plant tolerates the application of a herbicide that would otherwise harm or kill it.

All biotechnology, classical and modern, refers to "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services (OECD, 1989). Modern biotechnology has been referred to as the next green revolution, the gene revolution and the bio revolution because it has tremendous potential to develop crops with significantly improved agronomic traits such as drought resistance, virus resistance and insect resistance. It remains to be seen whether biotechnology will live up to these expectations, as some products have already proven to be more difficult to develop and required more time and resources to reach commercialization than first anticipated (Rissler and Mellon, 1996). The unique

set of regulatory, legal, ethical, environmental and economic concerns that surround biotechnology products due to their transgenic nature also create additional hurdles that must be overcome.

Public perception and consumer acceptance of biotechnology have and will continue to play a significant role in the success of transgenic products in the marketplace. A survey conducted in 1993 in Canada found that the public was unsure whether biotechnology will be beneficial or dangerous to society, and that only gene transfers involving plants were acceptable to a majority of the population (Decima Research, 1993). Similar public attitudes are found in the United States, but recent surveys in Europe indicate that up to 85 percent of consumers would not eat or purchase genetically altered food if given the choice (Leopold, 1995; Wadman, 1996).

A public unsure of biotechnology has contributed significantly to the ongoing debate regarding its potential risks and benefits. Some groups opposed to biotechnology have played to the public's concerns and general lack of in-depth knowledge on the subject in an attempt to convince as many people as possible it is something they should oppose. Other biotechnology opponents take a different route, discussing possible negative socioeconomic implications in Third World countries, the impact on nonfarm rural areas in industrialized countries and the long term effects of most biotechnology research being conducted in the private sector (Buttel, 1989).

Biotechnology proponents generally consist of the scientists, institutions and companies engaged in biotechnology research. In his seminal 1985 article in *Science*, Winston Brill stated that the economic and environmental benefits expected from biotechnology are great and should be considered in relation to the potential risks. Brill's approach to assessing the risk of recombinant organisms was to compare them to the products of traditional plant breeding. This approach led him to conclude that since biotechnology products are the result of transferring only a few genes whose functions are known, they pose no greater risk than traditional plant breeding, where scientists do not know exactly how many or which specific genes become part of a new plant variety. It is also argued that this technology could reduce the amount of pesticides applied, reduce soil erosion and increase crop yields, thereby helping to preserve the cultivated land base for future generations and feed a growing world population.

As biotechnology research has moved from the laboratory to field trials to the marketplace, the focus of concern and the group raising the concern has also changed. Soon after Drs. Cohen and Boyer discovered the technique for recombining DNA, there was concern among some molecular biologists that organisms containing recombinant DNA (rDNA) could pose a danger to human health if they escaped from the laboratory. To prevent such an occurrence, the scientists wanted strict but voluntary safeguards implemented. In turn, this generated public and government concern, and led to the possibility of government regulation of rDNA research. The same scientists strongly objected

to this approach because of a perceived threat to their autonomy and regulation was never put in place (Buttel, 1993).

A new concern came to the forefront of public attention when field trials of transgenic crops began. The opposition this time came from environmental groups and even some scientists who felt the risks of field trials had not been adequately assessed (Thompson, 1990). These groups felt there was a considerable risk that novel genes would escape into the environment by crossing with related weeds, thereby creating uncontrollable weeds and upsetting the ecological balance of the region. Many plant breeding experiments have been conducted on this subject, however no black and white unconditional answer has emerged (Salisbury and Wratten, 1997). In order to provide comprehensive information on this subject, long-term field studies need to be undertaken.

The commercial availability of a few biotechnology-derived products has led to a third area of concern - whether there is a health risk to humans who directly or indirectly consume food consisting wholly or partially of transgenic ingredients. This concern stems in part from the use of antibiotic-resistant genes as marker genes¹, as some fear these genes will confer antibiotic-resistance to the animal or human who consumes a transgenic plant or animal containing such a gene. Human health concerns are currently a significant barrier to public acceptance of transgenic soybeans in Europe, as soybean

¹ Marker genes are transferred into an organism at the same time as the gene(s) which encode for the novel trait of interest (eg. herbicide-resistance). Scientists then test for the presence of the marker gene to determine whether the gene(s) of interest has been successfully transferred.

meal and oil are ingredients in over half the processed food on supermarket shelves. In one case where human health concerns proved valid, development of a transgenic soybean was halted when it was discovered that consumption of it caused allergic reactions in people allergic to Brazil nuts - the origin of the transferred gene (Stix, 1995).

In addition to environmental and human health concerns, modern biotechnology has also raised ethical concerns. All biotechnology research is opposed on an ethical basis by some people and organizations including Greenpeace and Jeremy Rifkin's Pure Food Campaign, while others oppose only certain types of gene transfer (between plants and animals, for example). For some, the ability to patent whole living organisms and naturally occurring organisms, which is possible in the United States, Australia and some other countries, also raises ethical concerns (Hoyle, 1995). Canada does not permit patenting of higher life forms, but is obligated to do so under the GATT and must declare its position on the subject to the World Trade Organization by 1999. An extreme example of a whole organism patent is the one held by Agracetus in the United States for all genetically engineered cotton seeds and plants, which is currently under review by the United States Patent and Trademark Office. The fears that this and other whole organism patents raise are that nature itself may fall under corporate control, and that valuable germplasm may be available only to those who can afford to pay licensing fees, which would disproportionately affect poorer countries (Thompson, 1990).

Modern biotechnology has also resulted in a great deal of litigation, especially in the United States. Virtually all transgenic crops contain several genes which are subject to patent protection, and their development usually depends on the use of one or more techniques that are also patented. This sets the stage for many patent infringement lawsuits, which often require significant monetary outlays. This is exacerbated by the fact that the United States Patent and Trademark Office generally uses a broad brush when issuing patents, leaving it up to the courts to exactly interpret the law and decide which patents are valid and which should be revoked.

The economic and policy issues raised by modern biotechnology vary by specific product. The introduction of recombinant bovine somatotrophin (rBST) prompted several studies on its potential economic effects in the dairy industry in North America. Ex ante studies suggested rBST injections would increase a cow's milk production by anywhere from 10 or 15 percent to 40 percent (Geisler and DuPuis, 1989; Lesser et al., 1986). Magrath and Tauer (1986) then estimated that rapid adoption of rBST and the resulting production increase would lead to reductions in herd size, dairy farmers and milk prices. The dairy industry is heavily regulated in North America, and predictions of such structural changes led to discussions as to how government policy might be affected (Hueth and Just, 1987). Currently, rBST is used on only a small percentage of dairy cattle in the United States and is banned in Canada and Europe, mostly due to consumer apprehension regarding milk obtained from cattle injected with

rBST. Therefore, there has been limited potential for completing ex post studies that test the predictions of ex-ante studies.

The economic effects of transgenic crops will differ according to the purpose of a novel trait(s), for instance whether it significantly increases yield, makes the crop an input substitute, or adds value to the crop. Respectively, examples of such traits include transgenic hybrids, herbicide-resistance, and pharmaceuticals contained within harvested canola seed. Combinations of these traits are also possible, and herbicide-tolerant hybrids are already on the market. Hybrid varieties have some unique characteristics, such as hybrid vigour (higher yields) but the seed produced by hybrid varieties have poor germination and can not be used for seed in the following year. This makes it easier for plant breeders to control the distribution of these varieties. The economics of herbicide-tolerant, insect-tolerant and end-use specific varieties, however, are more uncertain as they are new technologies that have not been used by producers until now. For each of these technologies, the benefits and the risks must be weighed against each other to determine if there will be a net benefit or a net loss to producers and to society.

1.2 Problem Statement

The economic issues of transgenic herbicide-tolerant (HT) canola will be the focus of this study, specifically western Canadian canola production. The

relative ease with which canola can be genetically manipulated means that it was one of the first transgenic crop to clear all Canadian regulatory hurdles and several companies now have herbicide-tolerant canola varieties on the market.

Canola is an economically important crop to prairie producers, worth \$1.9 billion in farm cash receipts in 1996 (Statistics Canada, 1997), and herbicide-tolerant canola will not be adopted by producers unless it is profitable for them to do so. Therefore, the principal aim of this study is to determine whether HT canola will be a profitable technology for canola producers. Potential profitability from the perspective of individual producers comprises one part of this question, however the larger issues of consumer rejection of transgenic crops, gene introgression and structural changes in agriculture input industries, which affect the profitability of HT canola producers as a group, must also be examined.

1.3 Objectives of the Study

The overall objective of this thesis is to evaluate economic effects of three aspects of transgenic herbicide-tolerant canola from a producer welfare perspective. The specific objectives are as follows:

- i) to review all of the relevant literature;
- ii) to estimate if there is a net benefit or cost to canola producers in adopting herbicide-tolerant canola.

- iii) to construct a model which determines the changes in economic returns to canola producers if transgenic canola must be segregated to meet consumer demand;
- iv) to determine the potential for gene introgression and the resulting economic consequences of increased infestation of weeds related to canola; and
- v) to analyze the significant changes that have occurred in the agriculture biotechnology, seed and crop protection industries as they pertain to producer welfare.

1.4 Outline of the Study

The remainder of this paper is organized as follows. Chapter II contains a literature review, theoretical model, empirical analysis and discussion of a shift in the canola supply curve due to technological changes associated with growing transgenic canola, and of segregation of transgenic canola resulting from consumer preferences.

Chapter III contains a discussion of the potential for gene flow from herbicide-tolerant canola to its weedy relatives and the potential economic implications for producers of herbicide-tolerant wild mustard infestation in canola.

In Chapter IV the past, present and future of the agriculture biotechnology, seed and crop protection industries are examined, with a specific focus on canola. An analysis of the changes that have taken place in these sectors are then presented from a producer welfare perspective.

Chapter V summarizes and ties together the results of the preceding three chapters to provide overall conclusions regarding the economic implications of transgenic herbicide-tolerant canola for producers, and outlines some of the limitations of this study.

CHAPTER II

ECONOMIC IMPACT OF CONSUMER REJECTION OF TRANSGENIC CANOLA

2.1 Introduction

This chapter looks at the potential economic impact of consumer rejection of transgenic canola in a valuable export market for Canadian canola. The first section is a discussion of the structure of the Canadian domestic and export canola markets and the potential benefits and costs of herbicide-tolerant canola, which provides the framework for the theoretical model and empirical analysis. The remaining sections contain a review of relevant literature, theoretical model, empirical analysis and discussion, respectively.

2.1.1 Canola Domestic and Export Markets

Canola has increased steadily in economic importance to producers in western Canada, where the majority of canola is grown in Canada. In 1965 canola acreage comprised less than five percent of total cultivated area in western Canada. However, record low wheat prices and high canola prices in

the early 1990's spurred canola acreage increases to a peak of 14 percent of cultivated land in 1994, or approximately 14 million acres, worth \$2.155 billion to producers (Cansim, 1997). Canola has been adopted to the extent that crop rotation considerations are constraining further expansion due to disease problems in certain areas, evidenced in part by a decline in canola acreage in 1995 and 1996 from 1994 levels (Cansim, 1997).

Traditionally, a significant proportion of Canadian canola production has been exported and Japan the largest buyer. However, this situation has changed recently as Canadian production increased significantly and Europe, which imported almost no canola before 1992, became a major buyer. Brazil and the United States have also substantially increased their purchases of Canadian canola since 1992. In the 1985/86 crop year, 42 percent of canola production was exported, 90 percent of which was destined for Japan. In the 1994/95 crop year, exports accounted for 60 percent of production, 25 percent of which went to Europe and only 40 percent to Japan (Canada Grains Council, 1995).

The domestic crush demand has also grown by close to 50 percent due to the construction of two large crushing plants on the prairies. Cargill Limited opened a facility near Saskatoon, Saskatchewan in August 1996 which has a capacity of 2000 tonnes per day. The second plant is being built near Winnipeg, Manitoba by Canadian Agra, a private Canadian company. Its initial capacity will be 1000 tonnes per day, but the company plans to double this in

the future (Wensley, 1996). Previous to the entry of these firms, seven oilseed crushing facilities existed on the prairies, with an estimated capacity of 6900 tonnes per day between them. Four facilities are controlled by CanAmera Foods, a 50/50 joint venture between Central Soya of Canada Ltd. and CSP Foods Ltd. Archer Daniels Midland (ADM), Canbra foods and Canola Industries Canada also each own one facility. The ADM plant at Lloydminster, Alberta is the largest in this group, with an estimated capacity of 1800 tonnes per day at their Lloydminster, Alberta plant (Wensley, 1996).

2.1.2 Ex Ante Benefits and Costs of Transgenic Herbicide-tolerant Canola

Currently the benefits and costs of transgenic herbicide-tolerant canola (and other crops) are more theoretical than empirical, and are a combination of environmental, agronomic and economic factors. The technology is not likely to revolutionize canola production or weed control, but rather provide producers with another weed control option.

Presently weed control in western Canada relies primarily on the use of herbicides. There are eight major groups of herbicides, which are distinguished by their mode of action, or the physiological method by which a plant is killed. The groups are identified by a number between one and eight, each referring to a particular mode of action. Herbicides that do not belong to any of the eight groups, are referred to as Ungrouped or Other Herbicides (Manitoba

Agriculture, 1996). These groups are listed in Table 2.1, along with the brand names of herbicides that belong to each group. It is also important to note that herbicides belonging to the same group may not control the same weed spectrum or have the same crop safety, and that some herbicides have more than one mechanism of action.

Table 2.1: Herbicide Groups Based on Mechanism of Action

Group 1 (contain ACCase grasskillers) Achieve, Hoe-Grass II, Horizon, Prevail, Poast, Triumph Plus*, Puma, Laser, Champion Plus*	Group 2 (contain ALS/AHAS Inhibitors) Ally, Assert, Triumph Plus*, Muster, Pursuit, Refine Extra, Champion Plus*	Group 3 (contain dinitroanilines) Advance, Edge, Rival, Treflan, Bonanza, Fortress*	Group 4 (contain growth regulator herbicides) 2,4-D, Buctril M*, Banvel, Champion Plus*, Dyvel, MCPA, Laser*, Lontrel, Prevail*, Target	
Group 5 (contain triazines) Bladex, Lexone, Sencor, Atrazine	Group 6 (contain bromoxynil) Buctril M*, Hoe-Grass II*, Pardner, Laser*, Thumper*	Group 7 Lorox, Afolan, Linuron	Group 8 Avadex BW, Avenge, Fortress	Un-grouped Roundup Eptam, TCA, Liberty, Basa-gran, Mataven

* These products contain more than one active ingredient
Source: Manitoba Agriculture (Manitoba Agriculture, 1996)

Herbicide groups play an important role in weed management, as using the same herbicide year after year on the same field will likely cause the development of herbicide-resistant weeds. Such weeds originate from a spontaneous genetic mutation in one or more plants which makes them

resistant to a herbicide they have come in contact with - the basis of 'survival of the fittest'. Continued application of the herbicide to which these plants are resistant, instead of one that they are still susceptible to, means that the resistant population grows and reproduces. This is why farmers are told to use herbicides from different groups from one year to the next, commonly referred to as herbicide rotation, to prevent the development of herbicide-resistant weeds.

Many canola producers currently make more than one herbicide application on a field during the year. The first application is often a pre-emergent herbicide incorporated into the soil before the crop is planted. This entails some guesswork on the producer's part as to which weeds are likely to be a problem, and then which herbicide will provide the best control. Remaining applications are made after the crop and weeds have emerged, and the producer must choose from a myriad of herbicides which one(s) are best for their situation based on weed type and species, growth stage of the weeds and crop, herbicide tank mixability, herbicide cropping restrictions and cost.

Several transgenic HT canola varieties are used with the post-emergent herbicides Roundup® and Liberty, manufactured respectively by Monsanto and AgrEvo. When used with their complementary HT varieties, the non-selective foliar-applied nature¹ of these herbicides should allow for one-pass post-emergent weed control by killing all plants in the field except the crop. This would eliminate the need for a pre-emergent herbicide and reduce soil tillage, a

¹ Non-selective herbicides kill all plants they come into contact with, whereas some herbicides kill only a specific weed or group of weeds.

major contributor to soil erosion and loss of soil carbon. Herbicide-tolerant crops may be especially beneficial in tropical areas, where cultivation causes extreme soil erosion and degradation (Buddenhagen, 1996). Conservation tillage practices could also be successful in areas where this is currently impractical due, for example, to strong weed pressure. As well, less disturbance of the soil can improve water filtration and increase organic matter content in the soil, and the use of a non-selective herbicide eliminates much of the decision-making process surrounding herbicide choice.

Another potential benefit of HT canola involves herbicide rotation. Roundup® and Liberty both belong to the Ungrouped category of herbicides (but still have different modes of action), which makes the Roundup and Liberty-tolerant canola varieties attractive when it comes to herbicide rotation considerations. This is especially true for Liberty, since it is new to the herbicide market in western Canada and therefore weeds have not previously been exposed to its' particular mode of action. In contrast, Pursuit®, which is used with some HT canola varieties, is a Group 2 herbicide and populations of Group 2 resistant wild mustard, a common weed in canola, have been found in Manitoba (Manitoba Agriculture, 1996). This may deter some producers, especially those with Group 2 resistant wild mustard, from using Pursuit-tolerant canola.

Finally, HT canola may result in better weed control and yield gains, depending on the weed species that are present in a field and infestation levels of these weeds.

Opponents of herbicide-tolerant crops argue that their use could increase the amount of herbicide applied, which could increase herbicide residue in soil and groundwater, and extend the product life of environmentally-damaging herbicides. As almost all cropped cultivated land in North America and Europe currently receives at least one herbicide application, it is unlikely that the amount of herbicide applied in these regions could increase substantially for any reason. Since the technology allows for the use of one herbicide when two or more would have otherwise been used, less herbicide should in fact be applied on HT crops. This is supported by a 1993 study that concluded insect-resistant and herbicide-tolerant crops "have the potential to reduce pollution and mitigate the environmental impact of pesticides in agricultural production" (Hoyle, 1993). As well, proponents point out there is no incentive for companies to invest in the development of crops tolerant to a herbicide that may be taken off the market for regulatory/environmental reasons before (or soon after) the variety reaches commercialization. This negates increased use and/or product life of relatively more toxic herbicides, which are more likely to be taken off the market, as a result of growing herbicide-tolerant crops.

From an economic perspective, HT canola could increase profitability for producers, depending on the level of any agronomic gains realized and the cost of the technology relative to that of ordinary canola. Less obvious economic benefits could include reduced labour, fuel and machinery repair costs realized from fewer herbicide applications.

A further area of discussion centers on the possibility of outcrossing between a herbicide-tolerant crop and its weedy relatives and the presence of HT volunteers in the following crop, resulting in increased levels of herbicide-tolerant weeds. Studies which have been conducted on this subject provide conflicting results, and will be examined in greater detail in Chapter III.

2.2 Literature Review

This section reviews first the literature concerning returns to agricultural investment research and then specifically to agricultural biotechnology research and products. The economic theory that has been developed in these areas provides the basis from which the net benefits of transgenic herbicide-tolerant canola will be determined in the model which follows.

2.2.1 Returns to Agricultural Research

Agricultural research is an economic activity that involves the investment of scarce resources in the production of knowledge and innovation (Ruttan, 1982). This knowledge and innovation increases the productivity of producers through technological change and/or technical efficiency. Technological change commonly results in a shift in the supply curve (downward and to the right) or the demand curve (upward and to the right), depending on the effects of the technology.

A variety of methodologies and approaches have been developed in estimating the returns to technological change resulting from agricultural research and development. At their most basic level, all studies can be classified as either *ex-ante* or *ex-post*. The methodologies employed in *ex-ante* studies can be grouped into four groups: 1) scoring models which rank research activities; 2) use of benefit/cost analysis to determine rates of return; 3) simulation models; and 4) mathematical programming models which select an optimal mix of research activities (Norton and Davis, 1981). Studies of the *ex-post* type can be further subdivided into two major methodologies. The first uses the Marshallian concept of welfare and estimation of producers' and consumers' surplus. The second includes research as a variable in estimating a production function.

Another important classification is that of returns to aggregate agricultural research versus individual crop research. In the latter area, Griliches (1958) conducted a seminal *ex-post* study on returns to hybrid corn research in the United States. His methodology was indirect in that he estimated what the upward shift in the supply curve would be, relative to the present-day curve, if hybrid corn had not been developed and therefore yields had not significantly increased. To accomplish this, Griliches first assumed the market for corn was in equilibrium both before and after the effects of hybrid corn research took hold. He then assumed that corn output had increased by the same percentage for all producers, thereby producing a proportionate shift in the aggregate supply curve³. He further demonstrated that perfectly elastic and inelastic supply and demand elasticities did not have a large effect on the public rate of return to corn research, but did affect the distribution of benefits between consumers and producers.

Griliches' basic model has been modified and extended by many others over the years. Peterson (Peterson, 1967) studied poultry research in the United States; Ayer and Schuh (Ayer and Schuh, 1972) evaluated cotton research and production in Brazil; and Akino and Hayami (1975) investigated returns to rice breeding research in Japan. In Canada, Nagy and Furtan (1978) determined the internal rate of return to publicly-funded rapeseed breeding, and Zentner (1982) studied returns to wheat research and extension.

³ Since Griliches used perfectly elastic and inelastic supply curves, the shift was also parallel.

The estimation of gross benefits from research and development is dependent on the magnitude and the nature of the supply shift (pivotal, proportional, convergent or parallel) (Alston, 1991; Lindner and Jarrett, 1978). The size of total research benefits is also sensitive, but to a lesser degree, to the functional form that is used, and supply and demand elasticities (Miller et al., 1988). In determining the distribution of benefits between producers and consumers, the nature of the supply shift and the elasticities of supply and demand are most important. In general, when a parallel supply curve shift is assumed, the choice of functional form has little effect on the total estimated benefits and their distribution (Alston et al., 1995)

One of the most well-known examples of technical change embodied in seed is the Green Revolution. The development of wheat and rice varieties with significantly improved yield, disease resistance and lodging resistance resulted in dramatic yield and production increases in Mexico, Morocco, Egypt and many developing countries in Asia (Huke, 1985). Many *ex-post* studies have been conducted to determine the various economic and socio-economic impacts of the Green Revolution at the regional and national level.

2.2.2 Returns to Agricultural Biotechnology

Plant biotechnology research is similar to traditional plant breeding in that it results in technological change embodied in the genetic makeup of the seed. All studies that have been completed regarding the economic impact and

returns to agricultural biotechnology research are *ex-ante*, as only a few biotechnology products have been commercialized, and at this time none have been widely commercially available long enough for an *ex-post* study to be undertaken.

The potential returns to crop biotechnology research and development in Canada were first studied by Ulrich, Furtan and Downey in 1984, who looked specifically at rapeseed. At the time, the chief benefits of rapeseed biotechnology research were assumed to be higher yields achieved through development of hybrids and faster release of new varieties due to new techniques for plant regeneration. Using producer and consumer surplus as the measure of benefits, they concluded that the rate of return would be high enough to justify significant increases in funding for rapeseed biotechnology research. Farrell and Funk (1985) used the Delphi method to predict biotechnology's contribution to increased wheat, corn, barley and canola yields and then calculate the rate of return to biotechnology investment. It is interesting to note their assumptions that biotechnology was not likely to impact the cost per unit and/or the level of application of farm inputs, and that acreage of each of the four crops would change very little over the next twenty years, as the opposite has occurred.

More recently, some literature has emerged concerning the potential economic impact of specific products of agricultural biotechnology research. Kalter and Tauer (1987) provide a general discussion of economic impacts of

biotechnology at both the micro and macro levels of agriculture. At the micro level, the possibility is raised that hybrid corn containing high levels of tryptophan (an essential amino acid that is one of the limiting nutrients in animal feed) developed using biotechnology could reduce the demand for soybeans in animal feed, and use of recombinant bovine growth hormone may reduce demand for feed grains due to changes in feed rations. The difficulty in determining *ex-ante* the magnitude and nature of supply curve shifts resulting from biotechnology processes and products is noted, but the authors go on to state that a parallel shift in the total cost curve is "possible but not plausible", as this implies that marginal cost is not altered. At the macro level, they predict the chronic excess capacity of United States agriculture will continue, and that the nature of productivity increases will change from being relatively smooth and incremental to major jumps that correspond with scientific discoveries. Tauer (1988) reiterates the discussion regarding the character of supply shifts, and also points out some of the limitations of using econometrically estimated functions to determine economic impacts of biotechnology.

Crop- and trait-specific studies have been completed by Love and Tauer (1987) for virus-resistant tomatoes and potatoes and by Tauer and Love (Tauer and Love, 1989) for herbicide-tolerant corn in the United States. The former study found a small increase in economic surplus due to the virus-resistant nature of the crops, but did not factor in research costs. The latter study used an econometric simulation model representing crop and livestock production in

the United States to evaluate several scenarios involving various maximum rates of adoption, regional variation of adoption and cost per acre of the technology. In all cases, economic surplus increased but producer surplus declined as adoption of the technology increased production and lowered commodity prices.

2.3 Theoretical Model

The theoretical model that depicts the effects of farmers adopting transgenic canola varieties is shown in Figure 2.1. Suppose there is one market for canola, the private marginal cost for producing conventional canola varieties is MC_P and the social cost is MC_S . The difference between these two cost curves is the environmental cost associated with the use of herbicides. As discussed previously, there are at least two applications of herbicides in canola production, one pre-emergent and one post-emergent.

The introduction of transgenic canola will shift MC_P to MC'_P , by removing the cost of the pre-emergent herbicide application and because it is assumed that yields of transgenic varieties are higher than the yields of the conventional varieties in MC_P due to genetic improvement (ie. not better weed control). This yield increase is to be expected since the varietal registration system in Canada requires that new canola varieties be equal to or better than a benchmark variety in terms of yield, disease resistance, lodging and other important

characteristics. This means that new varieties with improved yields will continuously be introduced into the market.

The reduction in private costs will shift the social cost from MC_s to MC'_s , and less environmental degradation due to reduced herbicide usage will shift MC'_s to MC''_s . This results in a larger reduction in social costs than private costs from the adoption of the transgenic varieties.

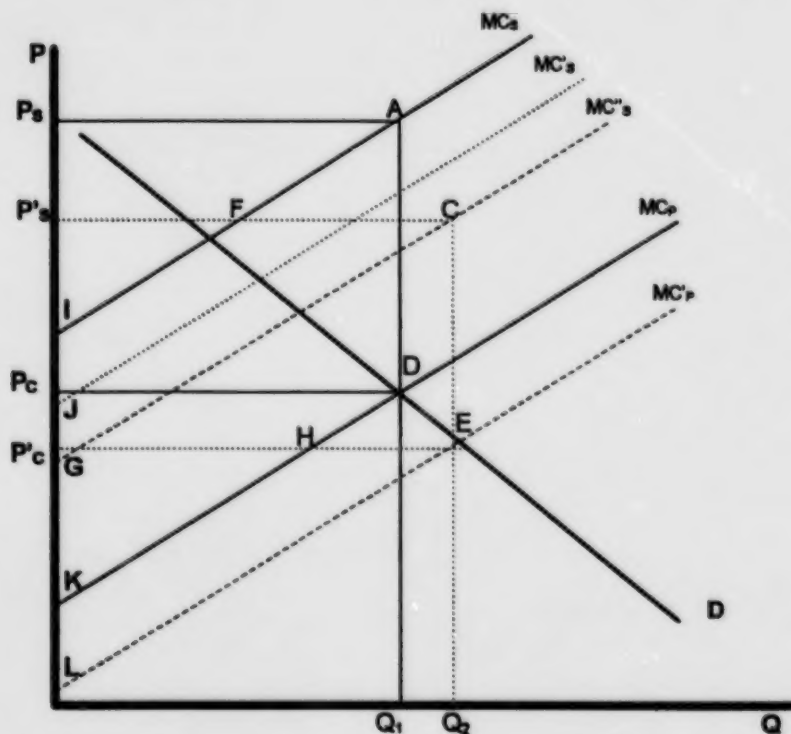


Figure 2.1 Private and Social Marginal cost Curve Shifts Due to Adoption of Transgenic Canola

For now, the risks associated with gene introgression from a HT canola crop into weedy relatives of canola controlled by the herbicide are ignored. If this did occur, the private costs would increase, causing MC_P to shift upwards.

The gross gain to society from the introduction of transgenic canola is area IFCG less area $P_sAFP'_s$, which will be positive. The gross private gains are area KHEL less area $P_cDHP'_c$.

Given an aggregate demand D for canola that does not differentiate between conventional and transgenic canola, the gross welfare effects of the adoption of transgenic varieties can be calculated for the private sector by comparing producer surplus at points D and E (equilibrium before and after adoption of transgenic varieties); and for the public sector by comparing consumer surplus at points A and C (Ulrich et al., 1986). This will indicate the magnitude of the gross welfare gain or loss producers and consumer realize as a result of the adoption of transgenic herbicide-tolerant canola. The net welfare effects would be calculated by subtracting the research and development (R&D) costs of HT canola from the total welfare gain. These costs are not estimated because of the ex-ante nature of the study. As well, a significant proportion of HT canola R&D costs have been incurred by the private sector, therefore benefits in the form of profits will flow to the companies who have invested in the technology.

Now suppose the demand for canola is made up of two markets instead of one. One market is comprised of countries whose consumers do not want to

eat genetically altered food (Market 1 in Figure 2.2). This market has an inelastic demand for canola, and imports just over half of total Canadian canola production. The other market is made up of all other purchasers of canola, who have no concern with genetically altered products, and has an elastic demand for canola (Market 2 in Figure 2.2). The aggregate demand for canola is now the sum of D_C and D_T , or D_A .

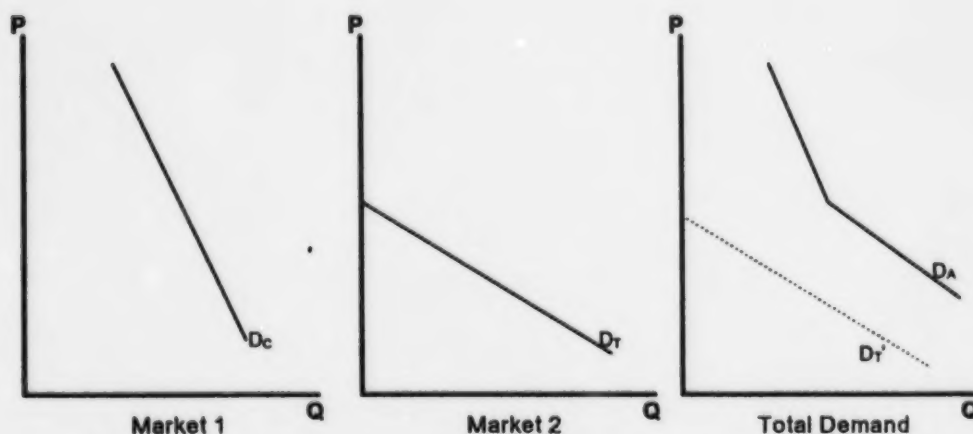


Figure 2.2 Demand for Canola

If Market 1 does not accept any canola from Canada because there is no guarantee that they will get only conventional canola, total canola demand then becomes D_T' , which is simply D_T . This assumes that the countries in Market 1 are able to move to a substitute product such as soybeans. A more likely scenario is Market 1 continues to purchase non-transgenic canola, but requires the segregation of transgenic and non-transgenic varieties at all stages of

production, marketing, processing and transportation. This is all based on the assumption that consumers will trust that segregation has indeed occurred.

The result of the production of both conventional and transgenic canola varieties is shown in Figure 2.3. The supply curve for canola previous to the introduction of transgenic varieties is shown as S_0 , and represents all canola producers. After transgenic varieties are planted by some farmers, this supply curve no longer represents all producers because of the difference in marginal cost between conventional and transgenic varieties. This means that there are now two supply curves, one for conventional canola varieties and one for transgenic varieties. The supply of conventional canola is represented by S_c , which has the same intercept as S_0 but a different slope that is determined by the proportion of conventional canola produced relative to total production (this equates to a fixed acreage for a given yield, however yields vary for individual fields). The supply curve for transgenic canola is shown by S_T' , which is arrived at in two steps. The first is a pivotal shift of S_0 to S_T , whose slope is determined by the proportion of transgenic production relative to total canola production. The second step is a parallel shift from S_T to S_T' because of the cost benefit associated with growing transgenic varieties.

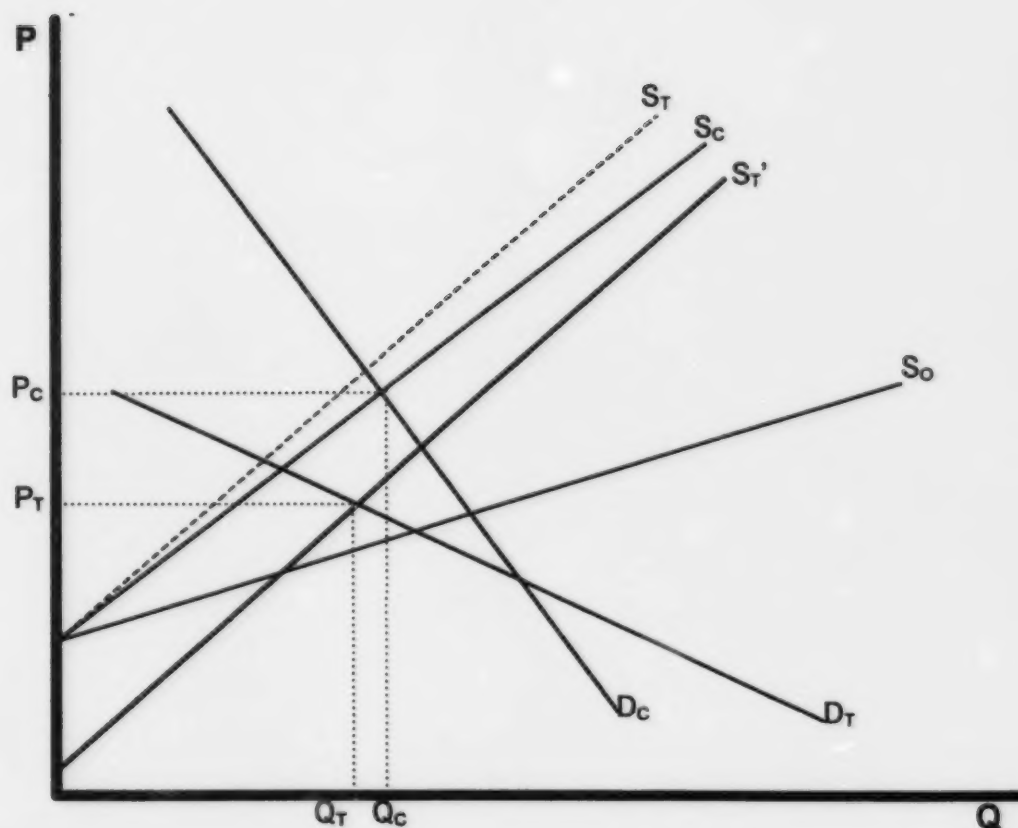


Figure 2.3 Demand and Supply for Transgenic and Non-transgenic Canola

The problem of consumer rejection of transgenic canola is shown in the model by introducing the demand curves shown in Figure 2.2. Under these conditions there are two equilibriums and two prices for canola. The intersection of D_C and S_C , the demand for and supply of conventional canola results in price P_C and quantity Q_C . The intersection of D_T and S_T' , the remaining demand for canola and the supply of transgenic canola, results in price P_T and quantity Q_T . Finally, the distance between S_T and S_T' , which

represents the marginal cost (MC) of conventional and transgenic canola, is equal to $P_C - P_T$, since both markets are in equilibrium and $P=MC$. Using these prices and quantities, total producer surplus will now be the sum of the producer surplus for conventional canola plus producer surplus for HT canola.

The cost of segregation may be borne by all canola production, only by transgenic production, or possibly only by conventional production. If transgenic production bears the costs, the MC curves in Figure 2.1 will shift upward by the per unit cost of segregation. This cost will reduce the benefit associated with growing HT varieties, which means there is less incentive for producers to plant HT canola⁴. Producers will cease to grow transgenic varieties if the segregation cost exceeds the economic benefit of HT canola. Alternatively, in order to maintain the market for their product, producers growing conventional canola may be responsible for ensuring the necessary segregation takes place. Depending on the magnitude of the cost, this may be a disincentive to growing conventional canola. Another possibility is that the firms who export canola charge a segregation fee to customers who want only conventional canola. The magnitude of the fee in comparison to the segregation costs will determine the price received by producers of conventional canola.

⁴ The private incentives to misrepresent canola in a segregated market have not been addressed in this model. If consumers create a premium for non-transgenic canola, ironically this increases the incentives for misrepresentation by producers, which could increase the cost of segregation and the probability of destroying this market.

2.4 Empirical Analysis

A computer spreadsheet was used to calculate P_C , Q_C , P_T and Q_T . The relevant parameters necessary for these calculations are given in Table 2.1 and other necessary statistics are given in Table 2.2.

Producer surplus prior to the introduction of transgenic varieties (Point D in Figure 2.1), given an average farm price of \$270/tonne and average production of 3.9 million tonnes was estimated to be \$401.9 million. The total producer surplus for the scenario depicted in Figure 2.3 depends on the magnitude of the shift from S_T to S_T' . Given an average yield of 22.78 bushels/acre and a cost benefit of \$15/acre resulting from lower herbicide costs, this shift will be \$28/tonne. At this magnitude of supply shift, Q_C is 1.64 million tonnes, Q_T is 2.48 million tonnes, P_C is \$282/tonne, P_T is \$254/tonne and total producer surplus is \$450.5 million. If the supply shift is increased to \$44/tonne to take into account a yield increase of approximately 10 percent, Q_C decreases to 1.61 million tonnes, Q_T increases to 2.65 million tonnes, P_C increases to \$289/tonne, P_T decreases to \$245/tonne and total producer surplus is \$479.4 million.

In order for this to represent a potential welfare gain, the change in producer surplus less segregation costs must be positive. It is assumed here that segregation costs are paid by all canola production. If segregation costs are \$2.50/tonne, then the calculation for a shift of \$28/tonne is as follows:

$$\$450.5 - \$401.9 - (\$2.50/t \times 4.13 \text{ Mt}) = \$38.275 \text{ million.}$$

If segregation costs are doubled to allow for public costs, there will still be a surplus of \$27.95 million. If Market 1 in Figure 2.2 ceases to import canola, producer surplus falls to \$256.84 million, production is 3.12 million tonnes and the price of canola decreases to \$167.66/tonne. Given these results the solution is to segregate the two types of canola in order to continue to sell to Market 1.

If only transgenic canola production pays the segregation cost of \$2.50/tonne, the supply shift will decrease to \$25.50/tonne from \$28/tonne, or to \$41.50/tonne from \$44/tonne. Respectively, this reduces the producer surplus for transgenic canola producers to \$267.02 from \$271.13 million and to \$298.06 from \$293.78 million.

The sensitivity of canola price and production to the decrease in cost of production was tested (Appendix A). As the magnitude of the supply shift increases, production of transgenic canola increases and P_T decreases, which results in less production of conventional varieties and an increase in P_C . This results in an increase in producer surplus for producers of both types of canola and therefore an increase in total producer surplus (Appendix A).

Finally, since yield is calculated in bushels per acre but the supply shift in Figure 2.3 is measured in dollars per tonne, different yield values will affect the magnitude of the supply shift (Appendix A). As yield increases, the supply shift becomes smaller for the same dollar per acre change in cost of production, which in turn results in lower producer surplus values.

Table 2.1 Parameters for Transgenic Canola Adoption

Parameter	Value
Domestic demand elasticity	-2.44
Export demand elasticity	-0.74
Supply elasticity	1.31
Farm Price for Canola	\$270/tonne
Production	3.9 million tonnes

Source: Malla (1995), author's calculations.

Table 2.2 Selected statistics for canola, Canadian prairie provinces

YEAR	PROD'N (mmt)	EXPORTS (mmt)♦	DOMESTIC CRUSH (mmt)♦	YIELD (bu/ac)	FARM PRICE (\$/mt)
1985	3.424	1.456	1.211	22.5	260
1986	3.5948	2.126	1.552	25.2	199
1987	3.6401	1.750	1.608	25.4	260
1988	4.1503	1.949	1.362	20.2	296
1989	3.1525	1.971	1.229	19.6	264
1990	3.1933	1.883	1.441	23	251
1991	4.1414	1.893	1.829	24	234
1992	3.8102	1.875	1.913	22.7	254
1993	5.4432	3.354	2.196	23.9	340
1994	7.1327	4.272	2.513	22.4	348
1995	6.3072	n/a	n/a	21.7	n/a
Average	4.3627	2.234	1.759	22.78	270.6

♦ Figures reported for crop year (August 1 to July 31), not calendar year.

Source: Cansim (1997), SAF (1995), Canola Council of Canada (1996b), Canada Grains Council (1995)

2.5 Summary

The model demonstrated that gross economic gains, as measured by producer surplus, could be achieved through the adoption of transgenic herbicide-tolerant canola on the Canadian prairies. These gains do not include the costs involved in developing HT canola, and depend on the magnitude of segregation costs. However, if transgenic and conventional varieties are not segregated, or if only transgenic varieties are grown, consumer rejection of transgenic canola may result in the loss of economically important export markets. In this situation the adoption of transgenic varieties may be blocked, as producer welfare declines by approximately one third relative to where no transgenic varieties are grown.

If segregation of conventional and transgenic varieties can be assured so that countries who do not want transgenic canola will still purchase conventional canola, the market will produce both varieties. In a segregated market where HT varieties realize a cost benefit of \$28/tonne, producer surplus is estimated at \$450.5 million, an increase of \$48.6 million or 12 percent over a market where no transgenic varieties are grown. Given a supply shift of the above magnitude, the change in producer surplus from current market conditions and net of segregation costs is positive, indicating that market segregation represents a potential pareto-improvement. If yield increases associated with transgenic varieties are taken into account, the net gain in producer surplus is even larger. If all canola production pays the segregation

costs, a minimum supply shift of approximately \$8/tonne must be achieved in order for the net change in producer surplus to remain positive. Alternatively, if only transgenic canola production pays the segregation costs, producers must realize a cost benefit from transgenic canola that at a minimum is equal to these costs. Otherwise there will be a net cost associated with growing transgenic canola.

CHAPTER III

POTENTIAL FOR GENE INTROGRESSION AND RESULTING ECONOMIC IMPLICATIONS

3.1 Introduction

The potential for gene transfer between herbicide-tolerant canola (or any other crop) and related weeds and herbicide-enforced selection for these plants is often raised as one of the potential risks associated with growing HT crops. While introgression of the gene(s) for a novel trait is possible through pollen transfer and hybridisation between the crop and weedy relatives, there are several mitigating factors that must be taken into consideration. More importantly, the consequences of introgression must be examined, as this is what will affect the profitability of HT crops (Dale, 1992).

This chapter therefore examines the possibility and consequences of hybridisation between HT canola and its weedy relatives. It begins by providing some basic information on canola from a plant breeding perspective, then outlines the major factors which may hinder or contribute to gene introgression

in the case of canola, discusses these factors in some detail and finally summarizes this information.

3.2 Background on Canola From a Plant Breeding Perspective

Canola belongs to the Cruciferae family of plants, which includes radish and mustard. It is important to note that canola differs from rapeseed as it has low erucic acid (less than 2 percent erucic acid as a percentage of total fatty acids) and low glucosinolate content in the residual meal (Downey and Rimmer, 1993). These characteristics make canola more desirable for feed, and food purposes.

Two canola species are grown in Canada: *Brassica napus*, or Argentine canola; and *Brassica rapa* (formally *Brassica campestris*), commonly known as Polish canola. Both species occur in winter and spring annual forms, although almost all acreage in Canada is planted to spring varieties. *B. napus* is self-pollinating although cross-pollination due to wind and insects may reach 36 percent, and *B. rapa* is self-incompatible or 100 percent cross-pollinated. Other members of the Brassica family include *B. juncea*, which is commonly grown in Western Canada and grown widely on the Indian subcontinent and in China; *B. nigra* (black mustard), a weed in Canada; and *B. carinata* (Abyssinian mustard) (Downey and Rimmer, 1993). Weedy relatives of canola include *Sinapis arvensis* (wild mustard), *Erucastrum gallicum* (dog mustard) and

Raphanus raphanistrum ssp. *Raphanistrum* (wild radish). *E. gallicum* is a self-compatible annual or winter annual species, most abundant in Manitoba and Saskatchewan and considered a secondary noxious weed (Lefol et al., 1996). *S. arvensis* is a common weed in western Canada, and presents particular problems in canola because the plant and the seed have similar morphology.

3.3 Factors Involved in Gene Introgression

Canola is one of several economically important crops, including sunflower, corn, rice and sugar beet, which have been known to hybridize with wild relatives (Lefol et al., 1996). The economic significance (if any) of gene introgression will be determined by the effect the resulting weed population has on the crop(s) in which it is a weed.

3.3.1 Possibility and Rate of Gene Introgression

The first and most important step in determining the effects of gene introgression is to assess the possibility and rate at which it is likely to occur. Possibility is determined by the sexual compatibility of species, which is assessed through plant breeding experiments where species are crossed in a laboratory (by hand pollination and sophisticated *in vitro* methods) and/or in a field setting. Determination of the rate must take into account such factors as

the vigour and fertility of any resulting hybrid plants, physical proximity of crop and weed, weed and crop densities, characteristics of the vegetation between donor and recipient populations, and the extent to which both species' flowering periods overlap² (Darmency, 1994; Salisbury and Wratten, 1997). For example, distance at which hybridisation is possible depends on whether plants are insect- or wind-pollinated and the species involved. One study found a negligible pollination frequency in oilseed rape at 50 m, most likely due to the fact that this crop is commonly pollinated by bees (Scheffler et al., 1993 in Sindel, 1997) . The results of several studies which address the possibility of gene introgression and are summarized below.

Lefol et al (1996) concluded that the possibility of hybridization occurring between *B. napus* and *Sinapis arvensis* under normal field conditions was very remote (probability less than 10^{-10}), and that the hybrid progeny had very low fitness. Extrapolating this probability of hybridisation, the authors calculated that two million ha of *B. napus* would produce 1000 hybrid progeny a year, however poor fitness would reduce the ability of these plants to survive and reproduce. Bing et al (1995) also concluded that gene introgression from *B. napus* to *S. arvensis* was very difficult under controlled, and therefore favorable, conditions. In another study, an investigation of gene transfer between *B. rapa* and the weeds *B. nigra* and *S. arvensis* found that such an event is possible between *B. rapa* and *B. nigra*, but unlikely to occur between *B. rapa* and *S.*

² For a detailed description of these and other factors, see Salisbury and Wratten, 1997.

arvensis (Bing et al., 1996). An Australian study also concluded that sexual incompatibility between *B. napus* and the weeds *S. arvensis*, *H. incana*, and *R. raphanistrum* will prevent gene transfer (Salisbury and Wratten, 1997).

One of the few studies to prove that gene transfer can occur was published by Danish researchers in 1996. They found that transgenic hybrid plants were produced spontaneously from a cross of glufosinate-tolerant *B. napus* and *B. rapa*. These interspecific hybrids were fertile, producing an average of 450 seeds per plant. The hybrids were backcrossed with *B. rapa* and some of the resulting plants displayed *B. rapa*-like morphology, possessed the same number of chromosomes as *B. rapa*³ and had pollen fertility in excess of 90 percent. Of the plants obtained from a second backcross between these plants and *B. rapa* plants, 42 percent were glufosinate-tolerant. As well, volunteer glufosinate-tolerant plants with *B. campestris* characteristics were found at the experiment site the following spring (Mikkelsen and et al, 1996).

Lefol et al (1996) studied the potential for gene introgression between the cultivated *Brassica* species (*B. napus*, *B. rapa*, and *B. juncea*) and *Erucastum gallicum* and *Raphanus raphanistrum*. Their experiments resulted in the recovery of four hybrid plants from the crosses *B. napus* x *E. gallicum*, *B. napus* x *R. raphanistrum* (two plants), and *B. rapa* x *E. gallicum*. The study found that the latter two hybrids were vigorous and fertile, and could successfully compete with the *Brassica* parent.

³ This is significant because *B. campestris* and *B. napus* have different chromosome numbers.

Hand pollination between *Brassica napus* and *Hirschfeldia incana*⁴ (hoary mustard), a Mediterranean weed, resulted in hybrids with reduced pollen fertility, but backcrosses were still deemed to be possible (Lefol et al., 1991). Further study determined that the weediness of these hybrids was not likely to be a concern in cultivated fields (Lefol et al., 1995).

3.3.2 Long-term Behaviour of Hybrid Weeds

The next step in determining the consequences of gene introgression is to utilize population genetic models. Such models require data on the number of seeds produced per plant, proportion of seeds that are dormant each year, proportion which is herbicide-sensitive, etc. to assess the behaviour of a plant population over a period of several years. These models have been by used weed and crop scientists to determine how herbicide and non-herbicide weed control methods affect herbicide-tolerant weed populations.

The information obtained from a population genetic model must then be combined with information regarding the weed's competition effects to determine its economic significance. For example, the presence of wild mustard in canola decreases harvested seed yield, reduces oil and oleic acid content and increases meal glucosinolate content and linolenic and erucic acid content of extracted canola oil and meal (McMullan et al.,⁴ 1993). These changes adversely affect canola oil and meal performance in food and feed

⁴Also known as *Brassica adpressa*.

applications. This is reflected in Canadian grading standards, which dictate that canola seed contaminated with greater than five percent wild mustard seed is considered a sample reject, and will not be accepted for delivery. Lesser amounts of wild mustard seed are considered dockage and the producer receives a lower grade for his/her canola according to the degree of contamination, which negatively affects the price they receive for the canola.

3.3.3 *Other Factors*

Where herbicide-tolerant crops are concerned, it is also important to note that resistance is only conferred to one herbicide, therefore volunteer HT plants that appear in consecutive years and weeds that may have gained the HT gene through introgression are still sensitive to other herbicides. Since it is now considered proper management to rotate herbicides among groups to prevent the development of herbicide resistant weeds through natural selection, farmers should be accustomed to not applying the same herbicide on the same field in consecutive years. Such action reduces the ability of the new weed population to multiply in the years that HT canola is not grown in a field⁵.

The above highlights another factor involved in the possibility of gene transfer - the individuality of producers' farming practices and field conditions. The density and type of weeds which existed in a field prior to the planting of

⁵ In the case of *Bt* or insect-resistant crops, government regulation mandates that producers of such crops follow specific rules which are designed to prevent the targeted insects from becoming resistant to the *Bt* toxin.

HT canola, its proximity to uncultivated areas, and whether a producer engages in traditional versus zero-tillage practices may affect the possibility and rate at which any gene introgression occurs.

The effect of weeds which acquire herbicide resistance and volunteer HT plants on the ecological balance in cultivated and uncultivated areas is also unknown. In order to determine the magnitude of such an effect, long-term ecological studies must be conducted in the habitat in which the weed is found.

3.4 Economic Implications of Gene Introgression for Producers

In the event that herbicide-tolerant weed populations develop (through gene introgression or due to volunteer HT plants), producers will be faced with additional costs to eliminate these weeds and decreased revenue if the infestation results in yield and/or quality losses. In general, herbicide-tolerant canola will no longer be profitable for producers to grow if the crop incurs economic losses which outweigh its economic benefits. In Chapter II, the average decrease in cost of production (economic benefit) was estimated to be \$28/tonne, or \$15/acre given a yield of 22.78 bushels/acre. Therefore, if weed infestation results in economic losses which exceed \$28/tonne, producers will no longer grow herbicide-tolerant varieties.

Tables 3.1 and 3.2 outline the economic losses which would result from a given infestation of wild mustard in canola for various yields and two different canola prices. The calculations show that the breakeven point of \$15/acre changes with yield and price variations and more importantly, that the producer's opportunity cost increases as yield and price increase. For example, at an infestation of 4 plants/m² and a price of \$6.14/bu, the loss per acre at a yield of 18bu/acre is \$11.05, but at a yield of 27 bu/acre the loss is \$16.58. If the price increases to \$9.82/bu, the same infestation will result in higher losses at all yield levels, as the loss on an 18 bu/acre yield is now \$17.68.

Wild mustard infestation may also result in enough dockage that the canola grades below No. 1, resulting in further economic losses. The threshold infestation resulting in greater than five percent wild mustard in harvested canola seed is reported as 20 plants/m² in one study (Canola Council of Canada, 1997) and 2 plants/m² in another study (ICMS Inc., 1992). Volunteer canola has also been shown to negatively affect plant density and seed yield in subsequent wheat and barley crops (Vera et al., 1987).

Table 3.1: Economic losses in canola resulting from wild mustard infestation, canola price \$270/t or \$6.14/bu

Infestation Plants/m ²	Percent Yield Loss	Economic Loss/Acre Given Yield of:			
		18 bu/ac	22.78 bu/ac	27 bu/ac	32 bu/ac
2	5	\$5.53	\$6.99	\$8.29	\$9.82
4	10	\$11.05	\$13.98	\$16.58	\$19.65
5	15	\$16.58	\$20.98	\$24.87	\$29.47
10	22	\$24.31	\$30.77	\$36.47	\$43.22
15	27	\$29.84	\$37.76	\$44.76	\$53.05
20	32	\$35.36	\$44.76	\$53.05	\$62.87

Source: Canola Council of Canada (1997), author's estimations.

Table 3.2: Economic losses in canola resulting from wild mustard infestation, canola price \$433/t or \$9.82/bu

Infestation Plants/m ²	Percent Yield Loss	Economic Loss/Acre Give Yield of:			
		18 bu/ac	22.78 bu/ac	27 bu/ac	32 bu/ac
2	5	\$8.84	\$11.18	\$13.26	\$15.71
4	10	\$17.68	\$22.37	\$26.51	\$31.42
5	15	\$26.51	\$33.55	\$39.77	\$47.14
10	22	\$38.89	\$49.21	\$58.33	\$69.13
15	27	\$47.73	\$60.40	\$71.59	\$84.84
20	32	\$56.56	\$71.58	\$84.84	\$100.56

Source: (Canola Council of Canada, 1997) , author's estimations

3.5 Summary

It is evident from the above discussion that gene transfer is not likely to create an immediate problem in the case of herbicide-tolerant canola. In the near future, herbicide-tolerant volunteer canola in subsequent crops may be a

larger problem than gene introgression, depending on the herbicide rotation that a producer has been following. The results of gene introgression studies completed to date indicate that the rate at which it occurs and the possible consequences are difficult to quantify, and therefore these numbers have not yet been determined. The economic consequences of gene introgression for producers (assuming the weeds cannot be fully controlled) will depend on the severity of herbicide-tolerant weed infestation levels, resulting yield losses and the level of dockage resulting from contamination of the harvested seed. Higher yields and canola prices increase producers' opportunity cost, as the revenue loss which results from yield losses and lower grades quickly erode the potential economic benefits of HT canola.

Finally, the variety and complexity of agronomic and economic factors which must be considered when attempting to determine the economic consequences of gene introgression reinforces the argument that risk assessment of transgenic plants must be carried out on a case by case basis (Dale, 1992).

CHAPTER IV

INDUSTRIAL ORGANIZATION OF THE CROP PROTECTION AND SEED INDUSTRIES

4.1 Introduction

Significant changes in the structure of the crop protection, seed and agriculture biotechnology industries have taken place since the early 1990's as a result of many mergers, acquisitions and formal collaborations. This chapter aims to discover what the economic effects of these changes may be for canola producers in western Canada. It begins by providing information on the nature of the global pesticide and Canadian canola breeding industries prior to the changes that have taken place, then details the more important changes that have occurred in these industries, and finally discusses the potential economic ramifications of these changes for canola producers.

4.2 Industry Background

4.2.1 Crop Protection Industry

The crop protection industry⁶ in western Canada is composed of roughly 10 companies, all of whom are subsidiaries of large multinational firms based in the United States or Europe. They include BASF, Bayer Inc., Dow Elanco Canada Inc., DuPont Canada Inc., AgrEvo Canada Inc., Monsanto Canada Inc., Rhone Poulenc, Rohm and Haas Canada Inc., Novartis, Cyanamid Crop Protection, and Zeneca. All of these companies have marketed crop protection products in the western Canadian market for at least a decade, and many are also involved in the development of pharmaceuticals, chemicals and/or synthetic materials. The largest firms in the western Canadian pesticide market (in no particular order) are Monsanto, DowElanco, Novartis and AgrEvo. Since there are relatively few firms, but they are very large, the global crop protection industry is rather oligopolistic. The industry is also very concentrated, as indicated by a 1985 study which reported that the four-firm and eight-firm concentration ratios for the agrichemical industry were 65 percent and 84 percent respectively (Office of Chemical and Allied Products, 1985).

Worldwide, the crop protection industry generated sales of over \$20 billion in 1988 (Cobb, 1992). In Canada, the most recent figures available are

⁶ Crop protection industry and pesticide industry are used interchangeably in the study to refer to herbicides, insecticides, fungicides and specialty pesticide products.

for 1995, which show that total pesticide sales rose 10 percent from the year previous to \$1.161 billion and product volume sold, as measured by active ingredient, increased by 8.5 percent. Herbicide sales represented 78 percent of this total, or \$906 million, followed by \$114 million of insecticide sales and \$73 million of fungicides. Sales of herbicides in western Canada were \$698 million, or 77 percent of the national total and canola herbicide sales grew by approximately \$50 million from 1994 to \$299 million (Crop Protection Institute, 1996).

Significant barriers to entry exist in the herbicide industry due to the large amounts of time and money that must be invested in research and development in order to bring a new product to the market. Currently, a new agrichemical takes 8 to 10 years and up to \$160 million in investment before any returns are realized (Cobb, 1992; IFA and GCPF, 1996; Miflin, 1996). In recent years, pesticide regulations have become more onerous as more and more information about the effects of a pesticide in the environment is required, and the requirements that a new pesticide must meet have become more stringent. This increases development costs and lengthens the time required to introduce and register a new product. The high costs associated with developing a new chemical means that companies direct their efforts towards products that will have a large market and a long product life.

In Canada, pesticide use increased by 7.6 percent per year from 1948 to 1991, primarily the result of increased herbicide application (Veeman and

Fantino, 1994). In most developed countries, cultivated land area is not significantly expanding and herbicides are applied to almost all cultivated acres, with the exception of organically grown crops. Consequently, even though sales continue to grow, the market for herbicides in North America, Japan and Europe is saturated. Growth in global herbicide demand will come from developing countries where industrialization, high rates of population growth and a lack of new land available for cultivation will necessitate improved crop yields (Office of Chemical and Allied Products, 1985).

In the past, herbicide use has created environmental and ecological problems. Presently however, the major problem associated with herbicide use is herbicide resistance of weeds (see Chapter II for a detailed discussion). For producers, this problem means increased costs and possibly lower revenues due to lower yields. For the crop protection companies, herbicide-resistant weeds result in a smaller market for herbicides (or herbicide groups) to which weeds are resistant, but could also mean increased sales of other products as producers seek alternative herbicides to combat this problem. In western Canada, common weeds such as wild oats (*Avena fatua*), green foxtail (*Setaria viridis*) and wild mustard have developed resistance to 10 or more times the normal application rates of Group 1 (wild oats and green foxtail) and Group 4 herbicides (wild mustard) (Manitoba Agriculture, 1996).

In 1997 approximately 70 herbicides are available to producers in western Canada. The most important characteristics of a herbicide from the

producer's perspective are: the weed(s) it controls; the crop(s) on which it can be used; the weed stage at which it is effective; the crop stage at which it is to be sprayed; and the cost. Other factors such as cropping restrictions in the following year, tank mixability with other herbicides, and herbicide resistant weeds also influence the purchase decision. The many possible combinations of these characteristics means that there are few products exactly the same but many that are similar to each other. Consequently, companies must be competitive when it comes to the cost of similar products and work to develop products that are better than those already on the market. This could mean a product that can be tank mixed with a wider range of other herbicides, control of a wider weed spectrum or easier handling.

In Canada, pesticides are marketed through the primary elevator companies' farm products retail centres and independent agri-retailers. Fertilizer and seed are also sold by many of these retailers, and custom application of pesticides and fertilizers is often a service available to farmers. Retailers play a significant role in the marketing of pesticides, as producers often personally know a retailer and will look to them for product recommendations. Many crop protection companies, therefore, provide various incentives to retailers to promote their products. The crop protection companies' sales representatives also play an important role as they deal with both producers and retailers throughout the year.

Data regarding margins on pesticides is highly confidential, but in general they are no different from most products on the market. Margins are highest when a product enters the market and offers a new and hopefully better alternative, and decline over time in order to remain competitive. The average lifetime of a product varies, depending on how successful it is. For example, Monsanto's flagship herbicide Roundup® has been marketed around the world for 25 years, but many pesticides do not enjoy a product life even half as long. While market dynamics may precipitate the disappearance of a product from the market, regulation, like the ban on the use of DDT, may also bring about the same result.

4.2.2 Canola Seed Industry

The canola breeding industry in Canada was comprised of only public institutions until the early 1980's, when private breeders began to enter the market. Some of the economic factors which contributed to this change include intellectual property protection afforded through the introduction of plant breeders' rights (PBR) legislation, a growing market for canola seed due to rising canola prices and depressed grain prices, the popularity of canola oil with consumers and very little competition in the industry. Pioneer Hi-Bred, which is "seldom interested in looking at anything new unless it has the potential of contributing at least one million dollars in profit per year" started a canola breeding program in 1988 for these and other reasons (Bolen, 1991). From a

plant breeding perspective, high seed multiplication ratio, good potential for hybrid development and the ability to develop specialty oils also make canola an attractive investment. (Forhan, 1993).

The public institutions involved in canola breeding are the Agriculture and Agri-Food Canada research stations at Saskatoon and Beaverlodge, Alberta, and the Universities of Alberta, Manitoba and Guelph. The major private breeders include Cargill Seed, Pioneer Hi-Bred, Svalof Weibull AB, Alberta Wheat Pool, Limagrain Genetics, Inc., Danisco Seeds, Zeneca Seeds and AgrEvo (Saskatchewan Agriculture and Food, 1997). Most of these companies are subsidiaries or divisions of foreign-based companies. As well, Pioneer Hi-Bred, Cargill and Groupe Limagrain (parent company of Limagrain Genetics, Inc.) are among the largest seed companies in the world (Le Buanec, 1996).

Worldwide, the total value of seed consumption is estimated at more than US\$50 billion annually. The United States has the largest commercial internal seed market, valued at US\$4.5 billion, followed by Russia, Japan and China (Le Buanec, 1996). The value of the seed market in Canada is small in comparison, due to the relatively small acreage of hybrid crops, which are highly profitable from the perspective of seed companies. The market for canola seed in Canada is worth approximately CAN\$150 million which makes it a very small segment of the world seed market.

Barriers to entry for conventional canola seed breeding are much less significant than those in the crop protection industry. Technical expertise is essential to variety development, but the necessary financial and physical capital commitments are generally less for technological and regulatory reasons. However, modern biotechnology techniques in plant breeding have changed this somewhat, as more expensive equipment is utilized that results in a speeding up of the regeneration and screening processes. Most varieties developed using conventional breeding need a minimum of six years to become commercially available, including a minimum two years of field trials.

Canola acreage has been at or near its peak for several years due to crop rotation considerations, however the canola seed market is far from mature. For example, Cargill Seed currently only markets other breeders' varieties, but should introduce the first varieties from its own breeding program onto the market in 1998. As well, most varietal development currently focuses on Argentine canola (*Brassica napus*) rather than Polish canola (*Brassica rapa*), which matures earlier but generally yields less than Argentine. Consequently, the potential exists for expansion of another significant aspect of the market. Biotechnology is largely responsible for the development of designer, or end-use specific canola varieties. These varieties contain nutraceuticals, pharmaceuticals such as human proteins, specialty oils and even plastic. They are grown under contract, usually only requiring a few acres, and are much more valuable than commodity varieties on a per acre basis. Many of the

private companies previously mentioned are engaged in this aspect of canola research and development and consequently this segment of the market is also expanding.

The marketing of canola seed varies between companies. Some, such as Saskatchewan Wheat Pool and Alberta Wheat Pool, are fully integrated in that they market and sell varieties they have developed. Other companies are involved in some combination of breeding and marketing. For example, Limagrain Genetics Inc. markets some of the varieties they develop, and contracts out the marketing of other varieties. There are also companies which function solely as a canola seed breeder (eg. Svalof Weibull Seed Ltd.) or marketer (eg. Proven Seed) through contracts. Public institutions also function solely as breeders. Certified seed growers are also an important part of the seed industry, as they are responsible for various stages of seed multiplication and may sell varieties directly from their farm. Seed margins, as with most products, are highest when a variety is first introduced and decline over time in order to remain competitive. Most seed is actually sold through the line companies' elevators or farm service centres and independent agri-retailers. As with pesticides, word of mouth and retailers' personal recommendations often play a significant role in producers' decision as to which variety he or she will purchase.

The influence of private sector involvement and competition in canola breeding is evidenced in many ways. The first private variety was registered in

1985 (Forhan, 1993). In 1997 there are 58 private canola varieties (45 Argentine and 13 Polish) available to producers, comprising 81 percent of licensed canola varieties (Saskatchewan Agriculture and Food, 1997). From the producer perspective, the wide selection of varieties affords the opportunity to select a variety best suited to their individual soil, climate and pest conditions. However from a breeder's perspective, the increased number of varieties available each year means that the profitable lifetime of a variety has decreased to three or four years from five or six years (Morgan, 1997). Private sector breeding has also benefited producers through a steady increase in the mean yield of Argentine canola varieties and the development of hybrid varieties (Forhan, 1993). Further, the vast majority of varieties developed by private breeders are protected by PBR (Saskatchewan Agriculture and Food, 1997).

4.3 Recent Changes

A great deal of consolidation took place in the global seed industry in the late 1980's (Appendix B), primarily a result of acquisitions by multinational corporations, including many agrichemical manufacturers (Fox, 1990). Since the early 1990's there have been many strategic collaborations, acquisitions and mergers transpire among and within the crop protection, agriculture biotechnology and seed industries (Appendix B). One of the reasons these

changes have occurred is the stagnant herbicide market in North America and Europe, which has pushed crop protection companies to find new products to market and/or new markets for existing products in order to increase market share and profits. As well, the institutional framework for transgenic crops, most importantly government regulation and intellectual property protection, has also been put in place in most industrialized countries. This is important because this framework is necessary for companies to successfully bring new products to the market.

The combination of these factors makes transgenic herbicide-tolerant crops an attractive way for agrichemical manufacturers to expand the market for their products that are already on the market. Just and Hueth (1993) refer to this as economies of scope in demand, meaning that two or more products can be marketed together for a greater net profit than would be achieved by marketing the products separately. The wide range of transgenic crops that are theoretically possible is a further incentive for seed and crop protection companies to engage in ag biotechnology research, as new products could be developed for markets these companies are already well established in.

To this end, some seed and pesticide companies started their own research programs for developing transgenic crops, while other firms' sole focus was ag biotechnology research. However, in order to expand and improve their research programs, many seed and crop protection companies have also acquired or merged with entire companies and/or parts of companies. For

example, Pioneer Hi-Bred acquired Biotechnica Canada's canola program in 1989 and then Allelix Crop Technologies, which had a strong canola hybrid development program, in 1990 (Bolen, 1991). More recently, AgrEvo GmbH, a German-based agrichemical manufacturer, initiated the purchase of Plant Genetic Systems International N.V. (PGS), a private Belgian company considered a world leader in plant biotechnology research and development.

This desire on the part of crop protection companies to develop HT and other transgenic crops is also evident in the actions of several corporations, most notably Monsanto Company, a crop protection and chemical company based in St. Louis, Missouri. In 1996 and 1997 Monsanto acquired the plant biotechnology assets of Agracetus and merged with Calgene, a major plant biotechnology company and developer of the Flavr Savr™ tomato.

During the same time period, Monsanto also expanded into the seed distribution and marketing arena through the acquisition of Asgrow Agronomics, a major U.S. soybean seed company; Holden's Foundation Seeds, the leading foundation seed corn company in the world; two companies who exclusively market Holden's products; and purchased \$30 million of equity in DeKalb Genetics Corporation, a large U.S. company involved in plant breeding and swine genetics. Monsanto now has a broad range of ag biotechnology research and patents, premium corn germplasm from which to develop transgenic varieties and a large seed marketing and distribution system. This expansion of Monsanto's agriculture biotechnology program has led to a decision to split the

company into two separately traded companies. A life sciences company will contain the crop protection and agriculture biotechnology businesses, and the second company will be based on the chemical business.

Also notable is the merger of Ciba-Geigy and Sandoz, two Swiss-based life sciences companies with pharmaceutical, crop protection and seed divisions, to create Novartis. Novartis Seeds (formed from the merger of the two companies' seed divisions) is now one of the world's three largest seed companies, and Novartis' agricultural biotechnology research brought the company the first U.S. patent for transgenic wheat in early 1997.

Many technology collaboration agreements, strategic alliances and joint ventures have also been entered into by several companies. These agreements often provide specific, temporary vertical and/or horizontal integration, allowing the companies involved to benefit from each other's expertise. For example, a research-oriented company may work with another company to market and commercialize specific products or technology for a designated length of time. Such an agreement exists between Saskatchewan Wheat Pool (SWP) and Calgene whereby Calgene's genetically engineered oil traits will be combined with SWP's canola germplasm to develop specialty canola varieties. SWP's established marketing and distribution capabilities will also be utilized in the production of these varieties for Calgene.

Intellectual property rights (IPRs) have also played a significant role in the recent flurry of mergers, acquisitions and collaborations. There are many

processes and genes protected by IPRs that are involved in the development of a plant with a novel trait. For example, Sehgal (Sehgal, 1996) lists eight IPRs needed to develop an insect protected plant. This makes licensing agreements necessary and also leads to many patent infringement lawsuits, which are very costly and time-consuming. As well, future transgenic crops are likely to contain more than one novel trait, which means that more IPRs will be involved in their development, making it will be an even more complicated and difficult process. For these reasons, it is a significant competitive advantage for a firm to hold many or all of the IPRs employed in their research and development program.

4.4 Implications for Producers

The net result of these corporate actions is that the structure of the seed and agricultural biotechnology industries have changed significantly. Prior to the development and commercialization of transgenic crops, ownership of seed companies by crop protection companies was the only link between these two industries. Now, in many cases, they are competitors in the same market. The various mergers and acquisitions described above have and others have reduced the number of firms in the seed, crop protection and ag biotechnology research industries, and many of the seed and crop protection firms which remain are larger in terms of both revenue and product line. These companies are therefore better equipped to deal with regulatory, research and

development, and any unforeseen costs than smaller firms in the market. An unsuccessful product will also have less effect on the profits of companies with a large product line.

An increased number of varieties also has other implications for producers. Herbicide- and insect-resistant varieties provide a wider range of alternatives to producers when they are deciding what to plant. Although this may require more management skills and/or time, producers are more likely to be able to choose a variety that has the specific features they are looking for.

The acquisition of agricultural biotechnology firms or assets by agrichemical companies raises the question of whether or not such companies will invest in ag biotechnology research that does not complement their existing product line. Just and Hueth (1993) investigated this question and found that a company or industry producing both biotechnology (eg. HT seed) and chemicals will produce more of the product that has a more inelastic demand, as this demand can be exploited more, than would separate companies or industries producing the same products.

The development of 'designer' canola (and other crop) varieties for specific and often non-traditional end-users has also brought about some vertical integration between seed companies and industries further downstream from producers. In some cases, the company which develops such a variety also owns the facility or assets necessary to extract and process the designer element from the crop. Producers who grow these varieties do so under

contract, and must segregate the crop at all stages of production. Many, if not all, of these varieties are worth significantly more than regular commodity varieties on a per acre basis. If the producer is unaware of the value of the crop he/she is growing, he/she may not be receiving as much as the processor or end-user is willing to pay. The designer variety aspect of the agricultural biotechnology market, in part due to its highly secretive nature, may be where companies can most effectively exert market power.

Fewer firms in the seed and biotechnology industries could lead to increased market power of the larger industry players. This may especially be true where one company supplies a herbicide-tolerant seed variety and its complementary herbicide to the market. However, the large number of herbicide- and insect-resistant varieties available for a number of crops from several different companies should mean there is competition between these firms to gain new customers and their loyalty. As well, it is producers and not consumers or other industries who benefit (in the short-term and the long-term) the most from such crops. If it is assumed that producers are profit maximizers, they will not purchase the technology unless it is economic for them to do so, and the extent to which firms can markup the price of transgenic seed is limited.

The empirical results from Chapter II (Appendix A) showed that the demand for transgenic HT canola seed declined as the economic benefit (production cost reduction) of these varieties declined. This means that firms supplying this seed face a downward sloping demand curve, which is

represented in Figure 4.1 by D_s . Most importantly, this curve indicates that demand for HT varieties would be zero if there was no economic benefit. Therefore the markup on transgenic HT canola seed must be less than the economic benefit.

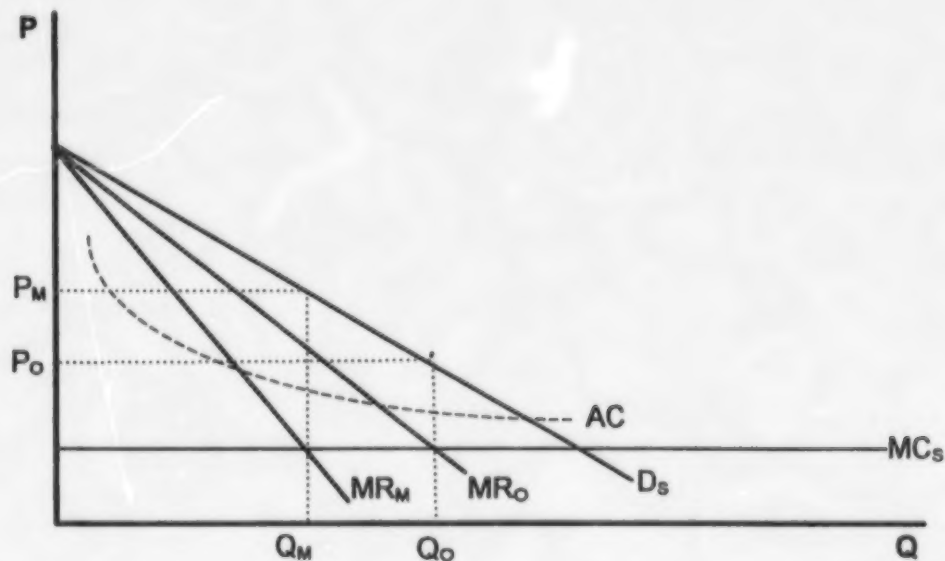


Figure 4.1 Demand for Transgenic Canola Seed

Figure 4.1 shows what happens to the price producers pay and the quantity supplied of transgenic canola seed if oligopoly or monopoly conditions prevail in the market instead of competition. In a competitive market, the price of transgenic seed would be equal to the marginal cost of producing the seed, MC_s . Oligopolistic conditions would increase price to P_O , and monopolistic behaviour would further increase price to P_M .

The extensive use of IPRs may also affect firms' pricing of transgenic crops by creating increasing returns to scale instead of constant returns to scale (Fulton, 1997). This means that firms have a strictly downward sloping average cost curve, shown in Figure 4.1 by AC, but this curve may remain above MC_s due to the high research and development costs incurred. Pricing at MC_s therefore would not allow firms to recover these costs so they will attempt to price above MC_s . If firms cannot price above MC_s , there is no incentive to carry out the research and development necessary to bring new technologies to the market.

Referring back to Figure 2.3, the effect of a markup on transgenic canola will reduce the magnitude of the supply shift (St to St') associated with HT varieties. This will leave producers with a smaller welfare gain than they would have if there was no markup, since producer surplus declines as the cost benefit declines.

The level of the markup on transgenic canola can be empirically shown by comparing the seed and herbicide costs of a HT variety to those of a non-HT variety for approximately the same level of weed control. The costs for Monsanto's Roundup® Ready canola are outlined in Table 4.1 along with those for Quantum, a non-HT variety that was very popular with producers in 1996, and the herbicides most likely to be used with a conventional variety.

Table 4.1: Cost comparison of HT and non-HT varieties

HT System - Roundup Ready		Non-HT System	
<i>Item</i>	<i>Cost/acre</i>	<i>Item</i>	<i>Cost/acre</i>
Seed (LG3295)*	\$20.58	Seed (Quantum)	\$12.00
Technology Use Agreement	\$15.00	Pre-emergent herbicide	\$13.50
Herbicide	\$8.00	Post-emergent herbicide	\$24.00
TOTAL	\$43.58	TOTAL	\$49.50

* Seed cost for both systems assumes a seeding rate of six pounds per acre.

Source: Beaumont (1997), Canola Council of Canada (1996a)

Table 4.1 shows there is a cost benefit to be had from growing HT canola, but it is less than the combined benefit of reduced herbicide costs and a 10 per cent yield increase, which is approximately \$29/acre. This indicates that there is a markup on HT canola, but it is not so high as to eliminate the cost benefit. It is also important to note that the calculations in Table 4.1 vary with seed variety and herbicides used. The cost of the LG3295 variety is representative of most HT varieties, with the exception of Quest, which costs approximately \$13/acre. With respect to conventional varieties, seed costs can range from \$8/acre up to \$20/acre although most varieties are close to Quantum in cost (Canola Council of Canada, 1996a). Also, herbicide costs for HT and conventional varieties may be higher than those in Table 4.1 depending on a producer's individual weed infestation problem.

The technology use agreement (TUA) is unique to Monsanto and Roundup® Ready varieties. The TUA is an attempt to separate the value of the

technology from the value of the seed, and also provides intellectual property protection for Roundup® Ready varieties. The TUA is a legal document that details what a producer is and is not allowed to do with the seed - most important of which is that harvested seed cannot be saved and then planted again at a later date. In contrast, the Liberty Link and Smart Canola HT varieties are marketed as a package so that farmers pay one price for both the seed (at a certain seeding rate) and the herbicide (given a specific application rate). Liberty Link canola has been advertised at \$32.50/acre, but this is the low herbicide application rate and many producers have found they require a higher rate, bringing the package price up to approximately \$40/acre. In general, it seems that companies marketing HT varieties are aiming for a package price of \$40/acre (Beaumont, 1997).

4.5 Summary

The many mergers, acquisitions and strategic collaborations that have transpired in the seed, crop protection and agriculture biotechnology industries could affect producers in a variety of ways. One effect could be an increase in the market power of firms supplying HT canola varieties, as there are fewer companies in the seed industries and the remaining firms are very large. An increase in the research and development of Polish varieties could take place, which would benefit producers. The development of end-use

specific varieties could also benefit producers because they are worth significantly more than commodity varieties, however this segment of the market is also likely to be subject to greater vertical integration varieties. Vertical integration could make price discovery of such varieties difficult or impossible and could also mean that producers are left out of the chain entirely.

Empirical analysis shows that a markup is present on the price of HT varieties, which varies according to the canola variety and herbicide(s) used by producers. This may indicate that some degree of market power is being exerted by the firms supplying HT canola seed. The cost of obtaining intellectual property rights may also be partly responsible for this markup, as the marginal cost of producing HT seed may not be high enough to allow firms to recover these research and development costs. A markup therefore could be viewed as an attempt to realize a return on firms' research investments. From the producer perspective, this markup means that they do not realize the full potential economic benefit of HT canola, and therefore producer surplus is lower than it could be, but still remains higher than it was prior to the introduction of HT varieties. The extent of the markup will depend on several factors such as producers' demand for HT canola, the market power that firms can exert and the difference between firms' average cost and marginal cost curves.

CHAPTER V

SUMMARY OF FINDINGS

6.1 Summary and Conclusions

The first wave of transgenic crops have now become widely available to producers around the world. In 1997, 10 million acres of herbicide-tolerant soybeans and 2.5 million acres of insect-resistant cotton was planted in the United States. This represents approximately 14 percent of the total acreage of each crop. In Canada, over 4 million acres, or almost one-third of all canola acres has been planted to herbicide-tolerant canola. These figures indicate that producers, and especially canola producers, have readily embraced this new technology.

Consumer acceptance has and will continue to play a significant role in the overall success of products developed using modern biotechnology, but for the most part this has not occurred as quickly as producer acceptance. Some are opposed to the use of biotechnology and the development of transgenic plants and animals on a moral and ethical basis. Others fear that the novel trait inserted into the genome of a major crop, such as herbicide-, insect- or virus-resistance, will be transferred to weeds related to the crop and create large

uncontrollable weed populations. Most recently, there has been some public uncertainty regarding the safety of foods and food ingredients derived from transgenic organisms for human consumption. This uncertainty has contributed significantly to the unsuccessful introduction of recombinant bovine somatotrophin and a move towards labeling regulations in Europe.

Human health concerns are also the reason that at least one of the largest importers of Canadian canola expressed uncertainty as to whether transgenic canola would be accepted for import. After conducting their own tests and scrutinizing Canada's regulations for the approval and release of plants with novel traits, the transgenic canola varieties available at the time were approved for import. The importance of this export market to the canola industry in Canada raised questions as to what the economic impact would be if this market disappeared.

The model developed in Chapter II demonstrated that if there was no segregation between transgenic and conventional canola, leading to the loss of an export market that pays a premium for canola, producer surplus would decline significantly, by approximately one-third. Alternatively, if the two types of canola could be segregated to ensure that a concerned importer would not receive transgenic varieties, producer surplus would increase, even when segregation costs are subtracted.

This welfare increase arises from an economic benefit to producers who grow transgenic varieties, which was estimated to be a lower cost of production

due to reduced herbicide costs and a yield increase resulting from genetic improvement. Other benefits such as lower machinery operating costs, improved weed control and reduced soil erosion could also be realized, but are more difficult to calculate because these characteristics are unique to each farm. The model also showed that the net gain in producer surplus disappears when the economic benefit shrinks beyond a certain point, and that canola production would increase as the benefit increases. Most importantly, the model demonstrated that consumer rejection of transgenic canola negatively affects producer welfare, due either to the loss of a market, or to the cost of segregation and the need to produce conventional varieties.

One of the possible costs associated with growing transgenic HT canola (or any HT crop) is gene introgression, or the transfer of the herbicide-tolerant gene from canola into its weedy relatives such as wild mustard, resulting in herbicide-tolerant weed populations. This is a concern because many producers around the world already have herbicide-resistant weeds in their fields as a result of genetic mutation, and are familiar with the additional costs incurred trying to eliminate these weeds.

There are many factors that must be considered when trying to determine the consequences of gene introgression. Hybridization between canola and its weedy relatives is necessary for gene introgression to occur, but there is consensus among the results of plant breeding experiments conducted to date that this is unlikely to occur for a variety of genetic and agronomic reasons. In

addition, hybrid plants that do develop usually have poor fitness and are sterile. Therefore even though gene introgression is theoretically possible, in reality it does not seem plausible.

However if gene introgression does result in herbicide-resistant weed populations that cannot be controlled, the economic losses which result would quickly cancel out the economic benefits of HT canola. These losses depend on the severity of the yield loss experienced and the level of dockage resulting from weed infestation, and the price of canola, although producers may also incur additional herbicide and management costs. Currently, volunteer HT canola plants are much more likely to occur than gene introgression, which could negatively affect the yield and grade of subsequent crops.

The many mergers, acquisitions and strategic collaborations that have occurred in and among the crop protection, seed and agriculture biotechnology industries have changed the relationships between these industries. The most obvious result of these changes is that agricultural biotechnology research and development has become a more important part of the activities of many crop protection and seed companies. In the past, interaction between the crop protection and seed industries has been limited to ownership of seed companies by crop protection companies. Now companies from these industries are competitors in the same market, and/or are collaborating on the research, development and marketing of a product. Seed company Pioneer Hi-Bred is competing with the crop protection companies Monsanto, AgrEvo and

Novartis in the market for herbicide-tolerant and/or insect-resistant varieties of several major crops. However, Pioneer Hi-Bred also works with Cyanamid, another crop protection company, in the development of certain herbicide-tolerant varieties.

From the perspective of canola producers, the changes in these industries currently mean that they are purchasing seed from a company which formerly only sold them pesticides, and that several herbicide-tolerant canola varieties, transgenic and non-transgenic, are now commercially available. The study also showed that the companies supplying HT canola varieties are not passing on all of the potential economic benefits of the technology to producers. The presence of this markup indicates that the market for HT canola is not a competitive one. This could be the result of firms exerting market power and/or an attempt by the same firms to recover some of the research and development costs incurred to bring the technology to the market.

The sum of the study results demonstrate that there are potential economic benefits to be had by producers who grow herbicide-tolerant canola, however the potential costs, especially those arising from the inability to control HT weeds, could outweigh the benefits. Thousands of producers have planted herbicide-tolerant canola in 1997, indicating they believe there is an economic benefit to be gained from growing these varieties. The number of acres planted to HT canola in future years will be an indication of whether or not this benefit was realized.

6.2 Limitations of the Study

The ex-ante nature of the study means that detailed data regarding the benefits and costs of HT canola is not available. Such data would allow a more accurate estimation of the supply shift in Chapter II. This also precludes the estimation of internal rate of return to investment in the development of the technology. Long-term studies are also needed to more accurately determine the possibility, rate and consequences of gene introgression.

Aside from this restriction, the study could be improved by performing additional sensitivity analysis for different elasticity values and alternative market shares for conventional and transgenic canola. The model in Chapter II also does not describe the current market situation because there is no segregation of harvested transgenic and conventional canola seed. Notwithstanding these improvements, this study makes a valuable and timely contribution.

REFERENCES

- Akino, M., and Y. Hayami, 1975. "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development." *American Journal of Agricultural Economics*, 57: 1-10.
- Alston, J. M., 1991. "Research Benefits in a Multimarket Setting: A Review." *Review of Marketing and Agricultural Economics*, 59: 23-52.
- Alston, J. W., G. W. Norton, and P. G. Pardey, 1995. *Science Under Scarcity. Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca and London, Cornell University Press.
- Ayer, H. W., and E. Schuh, 1972. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil." *American Journal of Agricultural Economics*, 54: 557-569.
- Beaumont, S. Personal Communication, July 9, 1997.
- Bing, D. J., R. K. Downey, and G. F. W. Rakow, 1996. "Assessment of transgene escape from *Brassica rapa* (*B. campestris*) into *B. nigra* or *Sinapis arvensis*." *Plant Breeding*, 115: 1-4.
- Bing, D. J., R. K. Downey, and G. F. W. Rakow, 1995. "An evaluation of the potential of intergeneric gene transfer between *Brassica napus* and *Sinapis arvensis*." *Plant Breeding*, 114: 481-484.
- Bolen, C. D., 1991. New Crops from a Seed Company Perspective, ed. J. Janick, and J. E. Simon. Indianapolis, Ind., John Wiley and Sons, Inc., pp. 685-659.
- Buddenhagen, I. W., 1996. "Modern Plant Breeding: An Overview." In *Biotechnology and Integrated Pest Management*, ed. G. J. Persley, pp. 205-207. Cambridge, CAB International.
- Buttel, F. H., 1993. "Ideology and Agricultural Technology in the Late Twentieth Century: Biotechnology as Symbol and Substance." *Agriculture and Human Values*, 10: 5-15.
- Buttel, F. H., 1989. "Social Science Research on Biotechnology and Agriculture: A Critique." *Rural Sociologist*, 9: 5-15.
- Canada Grains Council, 1995. "Canadian Grains Industry Statistical Handbook." . Canada Grains Council.
- Canola Council of Canada, 1996a. "Canola Production Centre Report." .

- Canola Council of Canada, 1997. *Growers Manual*. Winnipeg, Canola Council of Canada.
- Canola Council of Canada, 1996b. Selected Statistics.
- Cansim, 1997. Rapeseed - Canada and Provinces/Seeded Acreage, Canola - Prairie Provinces.
- Cobb, A., 1992. *Herbicides and Plant Physiology*. London, Chapman & Hall.
- Crop Protection Institute. "Industry Growing." *CAAR Communicator*, December 1996, p. 52-53.
- Dale, P. J., 1992. "Spread of Engineered Genes to Wild Relatives." *Plant Physiology*, 100: 13-15.
- Darmency, H., 1994. "The impact of hybrids between genetically modified crop plants and their related species - introgression and weediness." *Molecular Ecology*, 3: 37-40.
- Decima Research, 1993. "Report to Canadian Institute of Biotechnology on Attitudes Towards Biotechnology." Decima Research.
- Downey, R. K., and S. R. Rimmer, 1993. "Agronomic Improvement in Oilseed Brassicas." *Advances in Agronomy*, 50: 1-66.
- Farrell, C., and T. Funk, 1985. "The Determination of Ex-Ante Returns to Agricultural Research: The Case of Plant Biotechnology in Canada." *Canadian Journal of Agricultural Economics*, 33: 67-81.
- Forhan, M. "Canola Breeding Goes Private." *Canola Guide*, January 1993, p. 28-31.
- Fox, P., 1990. *Biotechnology and the Seed Industry*. Richmond, UK, PJB Publications Ltd.
- Fulton, M., 1997. *The Economics of Intellectual Property Rights: Discussion*. Toronto.
- Geisler, C. C., and M. DuPuis, 1989. "From Green Revolution to Gene Revolution: Common Concerns about Agricultural Biotechnology in the First and Third Worlds." In *Biotechnology and the New Agricultural Revolution*, ed. J. J. Molnar, and H. Kinnucan, pp. 221-233. Boulder, CO, Westview Press, Inc.
- Griliches, Z., 1958. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economics*, 66: 419-431.

- Hoyle, R. "Don't Dismiss Rifkin's Damning of Gene Patents." *Bio/Technology*, July 1995, p. 643-644.
- Hoyle, R. "Herbicide-Resistant Crops Are No Conspiracy." *Bio/Technology*, July 1993, p. 783-784.
- Hueth, D. L., and R. E. Just, 1987. "Policy Implications of Agricultural Biotechnology." *American Journal of Agricultural Economics*, 69: 426-431.
- Huke, R. E., 1985. "The Green Revolution." *Journal of Geography*, 84: 248-254.
- ICMS Inc., 1992. "Report on 1992 Trials (Project 9214) on Broadleaf Weed Competition in Canola." .
- IFA and GCPF, 1996. *Food for All: The contribution of the fertilizer and crop protection industries*, International Fertilizer Industry Association and and Global Crop Protection Federation.
- Just, R. E., and D. L. Hueth, 1993. "Multimarket Exploitation: The Case of Biotechnology and Chemicals." *American Journal of Agricultural Economics*, 75: 936-945.
- Kalter, R. J., and L. W. Tauer, 1987. "Potential Economic Impacts of Agricultural Biotechnology." *American Journal of Agricultural Economics*, 69: 420-425.
- Le Buanec, B., 1996. "Globalization of the seed industry: current situation and evolution." *Seed Science and Technology*, 24: 409-417.
- Lefol, E., V. Danielou, and H. Darmency, 1996. "Predicting hybridization between transgenic oilseed rape and wild mustard." *Field Crops Research*, 45: 153-161.
- Lefol, E., et al., 1995. "Gene dispersal from transgenic crops. I. Growth of interspecific hybrids between oilseed rape and the wild hoary mustard." *Journal of Applied Ecology*, 32: 803-808.
- Lefol, E., et al., 1991. *Escape of Engineered Genes From Rapeseed to Wild Brassicaceae*, vol. 3. Brighton, England, British Crop Protection Council, pp. 1049-1056.
- Lefol, E., G. Seguin-Swartz, and K. Downey, 1996. "Sexual hybridisation in crosses of cultivated *Brassica* species with the crucifers *Erucastrum gallicum* and *Raphanus raphanistrum*: Potential for gene introgression." *Euphytica*, .

- Leopold, M., 1995. "Public Perception of Biotechnology." In *Genetically Modified Organisms: A Guide to Biosafety*, ed. G. T. Tzotzos, pp. 8-16. Wallingford, UK, CAB International.
- Lesser, W., W. Magrath, and R. Kalter, 1986. "Projecting Adoption Rates: Application of an *Ex Ante* Procedure to Biotechnology Products." *North Central Journal of Agricultural Economics*, 8: 159-174.
- Lindner, R. K., and F. K. Jarrett, 1978. "Supply Shifts and the Size of Research Benefits." *American Journal of Agricultural Economics*, 60: 48-58.
- Love, J. M., and L. W. Tauer, 1987. Crop Biotechnology Research: The Case of Viruses, A.E. Res. 87-15, Department of Agricultural Economics, Cornell University.
- Magrath, W. B., and L. B. Tauer, 1986. "The Economic Impact of bGH on the New York State Dairy Sector: Comparative Static Results." *North Central Journal of Agricultural and Resource Economics*, 15: 6-13.
- Manitoba Agriculture, 1996. *Guide to Crop Protection*. Winnipeg, Manitoba Agriculture.
- McMullan, P. M., J. K. Daun, and D. R. D. Clercq, 1993. "Effect of wild mustard (*Brassica kaber*) competition on yield and quality of triazine-tolerant and triazine-susceptible canola (*Brassica napus* and *Brassica rapa*)." *Canadian Journal of Plant Science*, : 369-374.
- Miflin, B., 1996. "A View from Industry." In *Biotechnology and Integrated Pest Management*, ed. G. J. Persley, pp. 367-386. , CAB International.
- Mikkelsen, T., and et al. "The risk of crop transgene spread." *Nature*, p. .
- Miller, G. M., J. M. Rosenblatt, and L. J. Hushak, 1988. "The Effects of Supply Shifts on Producers' Surplus." *American Journal of Agricultural Economics*, 70: 886-891.
- Morgan, R. Personal Communication.
- Nagy, J. G., and W. H. Furtan, 1978. "Economic Costs and Returns from Crop Development Research: The Case of Rapeseed Breeding in Canada." *Canadian Journal of Agricultural Economics*, 26: 1,14.
- Norton, G. W., and J. S. Davis, 1981. "Evaluating Returns to Agricultural Research: A Review." *American Journal of Agricultural Economics*, 63: 685-699.
- OECD, 1989. *Biotechnology: Economic and Wider Impacts*. Paris, OECD.

- Office of Chemical and Allied Products, 1985. "A Competitive Assessment of the U.S. Herbicide Industry." . United States Department of Commerce.
- Peterson, W. L., 1967. "Return to Poultry Research in the United States." *Journal of Farm Economics*, 49: 656-669.
- Rissler, J., and M. Mellon, 1996. *The Ecological Risks of Engineered Crops*. Cambridge, MA, MIT Press.
- Ruttan, V. W., 1982. *Agricultural Research Policy*. Minneapolis, University of Minnesota Press.
- Salisbury, P. A., and N. Wratten, 1997. "Potential for Gene Transfer from Transgenic Canola (*Brassica napus*) to Related Crucifer Species Under Australian Conditions." In *Commercialisation of Transgenic Crops: Risk, Benefit and Trade Considerations. Proceedings of a workshop held in Canberra 11-13 March 1997*, ed. G. D. McLean, et al., pp. 95-113. Canberra, Cooperative Research Centre for Plant Science and Bureau of Resource Sciences.
- Saskatchewan Agriculture and Food, 1997. Varieties of Grain Crops 1997, The Advisory Council on Grain Crops.
- Saskatchewan Agriculture and Food (SAF), 1995. "Agricultural Statistics 1994." . SAF.
- Scheffler, J. A., R. Parkinson, and P. J. Dale, 1993. "Frequency and Distance of Pollen Dispersal from Transgenic Oilseed Rape." *Transgenic Research*, 2: 356-64.
- Sehgal, S., 1996. "IPR Driven Restructuring of the Seed Industry." *Biotechnology and Development Monitor*, 29: 18-21.
- Sindel, B. M., 1997. "Outcrossing of Transgenes to Weedy Relatives." In *Commercialisation of Transgenic Crops: Risk, Benefit and Trade Considerations. Proceedings of a workshop held in Canberra 11-13 March 1997*, ed. G. D. McLean, et al., pp. 43-82. Canberra, Cooperative Research Centre for Plant Science and Bureau of Resource Sciences.
- Statistics Canada, 1997. Farm Cash Receipts, January - December 1996. Ottawa, Statistics Canada.
- Stix, G. "A Recombinant Feast." *Scientific American*, March 1995, p. 38-39.

- Tauer, L., 1988. "Economic Changes From the Use of Biotechnology In Production Agriculture." *Journal of the Iowa Academy of Science*, 95: 27-31.
- Tauer, L., and J. Love, 1989. "The Potential Economic Impact of Herbicide-Resistant Corn in the USA." *Journal of Production Agriculture*, 2: 202-207.
- Thompson, P. B., 1990. "Biotechnology, Risk, and Political Values: Philosophical Rhetoric and the Structure of Political Debate." In *Biotechnology: Assessing Social Impacts and Policy Implications*, ed. D. J. Webber, pp. 3-16. Westport, Greenwood Press.
- Ulrich, A., W. H. Furtan, and A. Schmitz, 1986. "Public and Private Returns from Joint Venture Research: An Example from Agriculture." *The Quarterly Journal of Economics*, 101: 103-129.
- Veeman, T. S., and A. A. Fantino, 1994. "The Economics of Agricultural Chemical Use in Prairie Agriculture: Productivity and Environmental Impacts." . Department of Rural Economy, Faculty of Agriculture and forestry, University of Alberta.
- Vera, C. L., D. I. McGregor, and R. K. Downey, 1987. "Detrimental effects of volunteer Brassica on production of certain cereal and oilseed crops." *Canadian Journal of Plant Science*, 67: 983-995.
- Wadman, M. "Genetic Resistance Spreads to Consumers." *Nature*, 17 October 1996, p. 564.
- Wensley, M., 1996. "Institutional Change and the Canola Industry in Saskatchewan: Report Submitted to the Saskatchewan Agriculture Development Fund." . Univeristy of Saskatchewan.
- Zentner, R. P. "An Economic Evaluation of Public Wheat Research Expenditures in Canada." PhD, University of Minnesota, 1982.

APPENDIX A
SENSITIVITY ANALYSIS RESULTS

PRICE AND QUANTITY SENSITIVITY TO MAGNITUDE OF SUPPLY SHIFT

Supply shift	Price (\$/t)		Production (million tonnes)			
	Conventional Canola	Transgenic Canola	Conventional	Transgenic	Total	Percent conventional
\$4.00	\$271.73	\$267.73	1.692	2.241	3.933	43.02%
\$8.00	\$273.46	\$265.46	1.684	2.281	3.965	42.47%
\$12.00	\$275.18	\$263.18	1.676	2.322	3.998	41.92%
\$16.00	\$276.91	\$260.91	1.668	2.363	4.031	41.38%
\$20.00	\$278.64	\$258.64	1.660	2.404	4.063	40.85%
\$24.00	\$280.37	\$256.37	1.652	2.444	4.096	40.32%
\$28.00	\$282.09	\$254.09	1.644	2.485	4.129	39.81%
\$30.00	\$282.96	\$252.96	1.640	2.506	4.145	39.56%
\$32.00	\$283.82	\$251.82	1.636	2.526	4.162	39.30%
\$36.00	\$285.55	\$249.55	1.628	2.567	4.194	38.81%
\$40.00	\$287.28	\$247.28	1.620	2.607	4.227	38.31%
\$44.00	\$289.00	\$245.00	1.611	2.648	4.260	37.83%
\$48.00	\$290.73	\$242.73	1.603	2.689	4.292	37.36%
\$52.00	\$292.46	\$240.46	1.595	2.730	4.325	36.89%
\$56.00	\$294.19	\$238.19	1.587	2.770	4.358	36.43%
\$60.00	\$295.91	\$235.91	1.579	2.811	4.390	35.97%

CHANGE IN PRODUCER SURPLUS

Supply Shift	Producer Surplus (million dollars)		
	Conventional	Transgenic	Total
\$4.00	175.823	232.852	408.674
\$8.00	176.441	239.055	415.496
\$12.00	177.045	245.330	422.375
\$16.00	177.635	251.674	429.310
\$20.00	178.212	258.089	436.301
\$24.00	178.774	264.575	443.349
\$28.00	179.323	271.130	450.453
\$30.00	179.592	274.435	454.026
\$32.00	179.857	277.757	457.614
\$36.00	180.378	284.453	464.831
\$40.00	180.885	291.220	472.105
\$44.00	181.378	298.057	479.435
\$48.00	181.857	304.965	486.821
\$52.00	182.322	311.943	494.265
\$56.00	182.773	318.991	501.764
\$60.00	183.210	326.110	509.320

SENSITIVITY OF SUPPLY SHIFT TO VARIATION IN CANOLA YIELDS

Decrease in cost of production (\$/acre)	Supply shift at 15 bu/acre (\$/t)	Supply shift at 20 bu/acre (\$/t)	Supply shift at 22.78 bu/acre (\$/t)	Supply shift at 25 bu/acre (\$/t)	Supply shift at 30 bu/acre (\$/t)
\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
\$1.00	\$2.94	\$2.20	\$1.94	\$1.76	\$1.47
\$2.00	\$5.88	\$4.41	\$3.87	\$3.53	\$2.94
\$3.00	\$8.82	\$6.61	\$5.81	\$5.29	\$4.41
\$4.00	\$11.76	\$8.82	\$7.74	\$7.05	\$5.88
\$5.00	\$14.70	\$11.02	\$9.68	\$8.82	\$7.35
\$6.00	\$17.64	\$13.23	\$11.61	\$10.58	\$8.82
\$7.00	\$20.58	\$15.43	\$13.55	\$12.35	\$10.29
\$8.00	\$23.52	\$17.64	\$15.48	\$14.11	\$11.76
\$9.00	\$26.46	\$19.84	\$17.42	\$15.87	\$13.23
\$10.00	\$29.39	\$22.05	\$19.36	\$17.64	\$14.70
\$11.00	\$32.33	\$24.25	\$21.29	\$19.40	\$16.17
\$12.00	\$35.27	\$26.46	\$23.23	\$21.16	\$17.64
\$13.00	\$38.21	\$28.66	\$25.16	\$22.93	\$19.11
\$14.00	\$41.15	\$30.86	\$27.10	\$24.69	\$20.58
\$15.00	\$44.09	\$33.07	\$29.03	\$26.46	\$22.05
\$16.00	\$47.03	\$35.27	\$30.97	\$28.22	\$23.52
\$17.00	\$49.97	\$37.48	\$32.90	\$29.98	\$24.99
\$18.00	\$52.91	\$39.68	\$34.84	\$31.75	\$26.46
\$19.00	\$55.85	\$41.89	\$36.78	\$33.51	\$27.92
\$20.00	\$58.79	\$44.09	\$38.71	\$35.27	\$29.39
\$21.00	\$61.73	\$46.30	\$40.65	\$37.04	\$30.86
\$22.00	\$64.67	\$48.50	\$42.58	\$38.80	\$32.33
\$23.00	\$67.61	\$50.71	\$44.52	\$40.56	\$33.80
\$24.00	\$70.55	\$52.91	\$46.45	\$42.33	\$35.27
\$25.00	\$73.49	\$55.12	\$48.39	\$44.09	\$36.74
\$26.00	\$76.43	\$57.32	\$50.32	\$45.86	\$38.21
\$27.00	\$79.37	\$59.52	\$52.26	\$47.62	\$39.68
\$28.00	\$82.31	\$61.73	\$54.20	\$49.38	\$41.15
\$29.00	\$85.24	\$63.93	\$56.13	\$51.15	\$42.62
\$30.00	\$88.18	\$66.14	\$58.07	\$52.91	\$44.09

APPENDIX B

**CONSOLIDATION IN THE SEED, CROP PROTECTION AND
AGRICULTURAL BIOTECHNOLOGY INDUSTRIES**

CONSOLIDATION IN THE SEED INDUSTRY

Company	Company Acquired	Year
BioTechnica (US)	McAllister Seed (US)	1987
	Herried Seeds (US)	1987
	Horizon Seeds (US)	1988
	Flanagan Soybean Research (US)	1988
	Plant Science Research (US)	1988-
		89
	J M Schultz Seed (US)	1989
	Donley Seed (US)	1989
Booker (UK)	Daehnfeldt (DK)	1988
Calgene (US)*	Stoneville Pedigreed Seed (US)	1987
	Plant Genetics (US)	1989
	Bioseeds International (US)	1990
	Desert Cotton Research and Development (US)	1988
Ciba-Geigy (SW)*	Funk Seeds (US)	1974
	New Farm Crops (UK)	1987
DLF-Trifolium (DK)	Daehnfeldt (DK)	1990
Dow Chemical (US)*	United AgriSeeds (US)	1987
ICI (UK)*	SES (B)	1987
	MMG (UK)	1987
	Contiseed (US)	1989
Limagrain (FR)	Nungesser (FRG)	1987
	J Picard & Co (UK)	1988
	GR8 division of Shissler (US)	1988
	Flora Frey (FRG)	1990
	AgSeed (Australia)	1990
	BioTechnica (US)	1993
	King Agro (CAN)	1994
Lubrizol (US)	Sungene Technologies (US)	1989
Montedison (US)	Plant Cell Research Institute (US)	1987

CONSOLIDATION IN THE SEED INDUSTRY, CONTINUED

Company	Company Acquired	Year
Rhone-Poulenc (FR)*	Clause (FR)	1989
Sandoz (SW)*	Rogers Brothers Seed Co. (US)	1975
	Northrup King (US)	1976
	S&G Seeds (NL)	1980
	Stauffer Seeds (US)	1987
	Productores de Semillas (SP)	1987
	Musser Seeds (US)	1987
	Coker's Pedigreed Seed (US)	1988
	Hillesnøg (SWE)	1989
Sanofi (FR)	Barbaret & Blanc (FR)	1987
	King Group (CAN)	1988
	Cambier (FR)	1989
	Caussade (FR)	1989
Unilever (UK)	PBI/NSDO (UK)	1987
	Barenbrug (NL)	1989
Upjohn (US)	Bruinsma Seed (NL)	1987
	Genecorp (US)	1989

* These companies also develop and market crop protection products.

Source: Adapted from Fox (1990).

**MERGERS, ACQUISITIONS AND STRATEGIC COLLABORATIONS IN THE
SEED, CROP PROTECTION AND AGRICULTURE BIOTECHNOLOGY
INDUSTRIES**

COMPANY	DATE	ACTION	COST
Monsanto	March 1996	Increased equity held in DeKalb Genetics to 10% of voting and 43% of non-voting shares	\$152 million
	April 1996	Acquired plant biotechnology assets of W.R. Grace & Co.	\$150 million
	Sept. 1996	Acquired Asgrow Agronomics from Empresas La Moderna (ELM)	\$240 million
	Sept. 1996	Entered into technology collaboration with ELM to become preferred provider of agronomic and quality traits developed through biotechnology	
	Jan. 1997	Acquired Holden's Foundation Seeds, Inc., Corn States Hybrid Service, Inc., and Corn States International	\$1.02 billion
	May 1997	Completed purchase of all Calgene Inc.'s outstanding shares	\$248 million
	July 1997	In the process of becoming two separately traded companies. One will be chemical based and the other life sciences based	
DowElanco	Jan. 1996	Acquired 9.5 million of 30.4 million shares in Mycogen from Lubrizol Corp.	\$126 million
	Dec. 1996	Controlling interest in Mycogen Corp. gained through purchase of shares from Pioneer Hi-Bred	\$16.8 million
	May 1997	Agreement signed with Ribozyme Pharmaceuticals, Inc. to develop and commercialize RPI's technology for agricultural applications	N/A

**MERGERS, ACQUISITIONS AND STRATEGIC COLLABORATIONS,
CONTINUED**

COMPANY	DATE	ACTION	COST
DowElanco, continued	May 1997	Dow Chemical Company to acquire Eli Lilly's 40% stake in DowElanco (joint venture formed in 1989)	\$900 million
Mycogen	1992	Acquired Agrigenetics Co., a division of Lubrizol Corp. and seventh largest seed company in the U.S.	unknown
	1995	Collaboration signed with Pioneer Hi-Bred to develop technology for insect-resistant transgenic crops	\$51 million (R&D funding and stock purchase)
	Jan. 1996	Acquired United AgriSeeds from DowElanco and \$26.4 million	4.5 million shares issued to DowElanco
	Jan. 1996	Purchased from Lubrizol certain oilseed technology rights	\$8 million
	1996	Acquired Morgan Seeds, third largest seed company in Argentina	
	Dec. 1996	Exchanged its European seed business and other assets for an 18.75% interest in Verneuil Holding, a major seed company in Europe	unknown
AgrEvo	August 1996	Acquired Plant Genetic Systems of Belgium, a leader in plant biotechnology research	\$550 million for 75% of shares
Novartis	Dec. 1996	Formed from largest corporate merger in history of Ciba-Geigy and Sandoz	Sales of \$24 billion in 1996
	Jan. 1997	Ciba Seeds and Northrup King Co. merge to form Novartis Seeds, Inc.	
	May 1997	Purchased Merck & Co.'s crop protection business	\$910 million
BASF	Sept. 1996	Purchased a portion of Sandoz' worldwide corn herbicide business (condition of Novartis merger)	\$780 million

**MERGERS, ACQUISITIONS AND STRATEGIC COLLABORATIONS,
CONTINUED**

Empresas La Moderna	Recent acquisitions include DNA Plant Technology, Asgrow Seed (from Upjohn Co.), Petoseed and Royal Sluis; gives it 22% of vegetable seed market in 110 countries	\$650 million for latter 3 companies only
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Source: Company news releases and other public corporate information.